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PRE-FOUNTAIN AND RECENT WEATHERING ON FLAGSTAFF MOUNTAIN NEAR BOULDER, COLORADO

BY ERNEST E. WAHLSTROM

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ABSTRACT

Decomposition of granodiorite underlying basal Fountain (Pennsylvanian) formation on Flagstaff Mountain near Boulder, Colorado, was the result of pre-Fountain, probably post-Madison weathering. Chemical and mineralogical studies indicate that the weathering took place in a humid, warm or hot climate and that laterization was the dominant process.

The results of pre-Fountain and recent weathering are compared and contrasted.

The red color of the Fountain formation is regarded as inherited from a deeply weathered extensive red-stained pre-Fountain regolith.

INTRODUCTION

On Flagstaff Mountain, just west of Boulder, Colorado (Fig. 1), basal Fountain arkose (Pennsylvanian) rests unconformably on a steeply dipping erosion surface

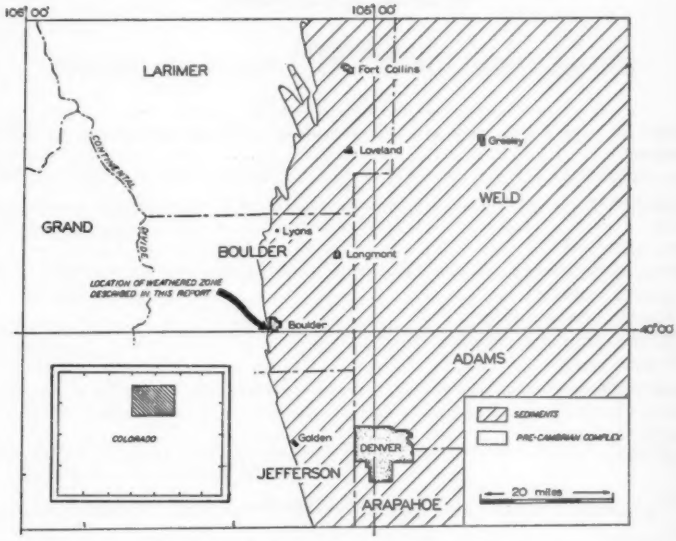

FIGURE 1.—*Outline map of north-central Colorado*
Showing location of weathered rocks described in this report.

which truncates the pre-Cambrian Boulder Creek granodiorite batholith. The contact between the Fountain arkosic sandstone and conglomerate and the granodiorite is well exposed in a road cut near the summit and on the east slope of Flagstaff Mountain, where the granodiorite shows two distinct types of weathering, one of recent origin and the other pre-Fountain. Samples from both fresh and weathered exposures of the granodiorite were analyzed chemically and mineralogically.

ACKNOWLEDGMENTS

The writer gratefully acknowledges the counsel of Professor W. O. Thompson of the Department of Geology at the University of Colorado, whose stimulating discussions and criticism have been of invaluable assistance in the preparation of the manuscript.

FOUNTAIN FORMATION

The Fountain formation in the vicinity of Boulder has been described by Fenneman (1905), Butters (1913), Tieje (1923), and Henderson (1920). It is composed of

coarse arkosic sandstone locally grading into quartzose conglomerates, sandstones, and shales. Fresh fragments of microcline are abundant, and mica is widespread, especially in the finer-grained portions. The color ranges from reddish brown through red to pink and is due to the reddish feldspar fragments and a cement of silica and iron oxides. A few beds of arkose and sandstone are nearly white.

Rapid lateral variation in thickness is the rule. In the vicinity of Boulder the average thickness is about 1000 feet. Cross-bedding, lenticular beds, and cut-and-fill structures are conspicuous. Abundant buried stream channels suggest a highland source to the west. Evidence points to a fluvial origin, and the Fountain formation has been interpreted as a series of coalescing alluvial fans deposited along the flanks of a north-south uplift.

McLaughlin (1947) states that in portions of the Colorado Springs quadrangle the Fountain formation rests conformably on the Glen Eyrie formation and elsewhere lies with angular unconformity on older Paleozoic formations or directly on eroded pre-Cambrian rocks. The youngest Paleozoic rocks beneath the unconformity are of Madison age. Fossils from the Glen Eyrie and Fountain formations "indicate that the two formations are equivalent to, or perhaps younger than, some part of the Des Moines series of the Pennsylvanian section of Kansas" (McLaughlin, 1947).

The widespread reddish color of the Fountain formation is inherited. Porous light-pinkish-gray to almost dead white layers are locally present and prove that the iron-oxide stain in the red and pink layers is not secondary.

PRE-CAMBRIAN ROCKS

The pre-Cambrian complex in the core of the Front Range west of Boulder consists of igneous and metamorphic rocks of Archeozoic and Proterozoic age. Tertiary stocks and dikes cut the older rocks. In the vicinity of Boulder three rock assemblages predominate (from oldest to youngest): the gneisses and schists of the Idaho Springs formation, the granodiorite and associated pegmatites of the Boulder Creek granodiorite batholith (by some authors called the "Boulder Creek granite batholith"), and the Silver Plume granite with its satellitic pegmatite bodies. The erosion surface at the base of the Fountain formation truncates each of these rocks at one place or another along the east side of the Front Range.

As the present study is confined to an examination of the contact between the Fountain formation and a portion of the Boulder Creek granodiorite batholith, only this rock will be described. An analysis of the granodiorite is given in Table 1.

In fresh exposures the granodiorite is a medium-gray to pinkish-gray, coarse-grained locally porphyritic rock in which the groundmass minerals average about 5 mm. in diameter.

Phenocrysts of microcline commonly are about 10–15 mm. in average diameter but locally are tabular and attain lengths of 30 to 40 mm. A gneissoid structure is generally apparent and is emphasized by the parallel orientation of flakes of biotite, needles of hornblende, plates of plagioclase, and tabular phenocrysts of microcline. In some exposures numerous schlieren and partly assimilated or recrystallized inclusions of Idaho Springs formation are abundant.

Under the microscope the following minerals, listed in order of decreasing volume percentages, are found: oligoclase (Ab_{75}), 35; microcline, 25; quartz, 20; biotite, 16; hornblende, 3; minor accessory minerals including apatite, zircon, sphene, and allanite, 1. Micrometric analyses using the Rosiwal technique do not yield consistent results because the rock is coarse-grained and porphyritic. The oligoclase is tabular,

TABLE 1.—*Granodiorite from Flagstaff Mountain*

Analyst: E. W. Wahlstrom

SiO_2	67.92	K_2O	4.38
TiO_2	0.55	H_2O+	0.89
Al_2O_3	14.70	H_2O-	0.36
Fe_2O_3	0.91	P_2O_5	0.18
FeO	2.61	CO_2	None
CaO	2.94	MnO	0.03
MgO	0.98		
Na_2O	3.31		99.67

unzoned, polysynthetically twinned, and in some thin sections shows a myrmekitic intergrowth near the rims of its crystals. The peripheries of many microcline crystals also show quartz-feldspar intergrowths in a micrographic pattern. Quartz is interstitial to microcline and oligoclase.

Biotite and hornblende, intimately associated in clusters of subhedral crystals, closely follow the contacts between quartz and feldspar grains. The mica is pleochroic in olive green and light yellowish brown. 2V is near zero, $\alpha = 1.587 \pm 0.003$, $\gamma = 1.621 \pm 0.003$. The hornblende is pleochroic in dark green and yellowish greens. An analysis of the biotite is given in Table 3.

Apatite, zircon, sphene, magnetite, and allanite are associated with the biotite and hornblende.

Numerous pegmatite and aplite dikes ranging from an inch to several feet in width intersect the granodiorite and apparently are genetically related to it.

WEATHERING

GENERAL STATEMENT

The pre-Fountain weathering is related to the surface beneath basal Fountain and is parallel to the Fountain-granodiorite contact (Fig. 2; Pl. 1, fig. 1). Residual masses of fresh granodiorite mark the lower limit of the pre-Fountain weathered mantle.

Recent weathering (Fig. 2) is related to the present land surface. The recent weathering has affected only the fresh granodiorite and has not resulted in any physical or chemical changes in the rocks altered by pre-Fountain weathering.

PRE-FOUNTAIN WEATHERING

General statement.—Pre-Fountain weathering in this area has affected the granodiorite to a depth of approximately 80 feet beneath and normal to the contact. This

FIGURE 1. VIEW LOOKING NORTHEAST AT WEATHERED GRANODIORITE EXPOSURE
In roadcut near the top of Flagstaff Mountain. A — Basal Fountain formation, B — Fountain-granodiorite contact, C — Red-stained rock, D — Bleached horizon, E — Residual boulder near base of bleached horizon, F — Brown-stained rock.

FIGURE 2. FOUNTAIN ARKOSE (RIGHT) RESTING ON RED ALTERED GRANODIORITE (CENTER) WHICH GRADES INTO BLEACHED ALTERED GRANODIORITE (LEFT).

PHOTOGRAPHS OF WEATHERED ROCKS

FIGURE 1. FRESH BIOTITE
Mica analysis no. 11. Mica is clear and unaltered.

FIGURE 2. MICA FROM BLEACHED HORIZON
Mica analysis no. 6. Shows considerable bleaching and dust of iron oxide.

FIGURE 3. MICA FROM BOTTOM OF RED-STAINED HORIZON
Mica analysis no. 4. Shows compaction resulting from leaching of adjacent minerals. Note numerous small hematite plates.

FIGURE 4. ALTERED MICA FROM TOP OF RED-STAINED HORIZON
Mica analysis no. 1. Mica is nearly colorless and is embedded in opaque matrix of iron oxides.

PHOTOMICROGRAPHS SHOWING PROGRESSIVE ALTERATION OF MICA

depth is nearly a maximum for the region. The rocks beneath the Fountain formation were examined in several other exposures along the east side of the Front Range, and nowhere was the weathering as extensive or as conspicuous as on Flagstaff Mountain.

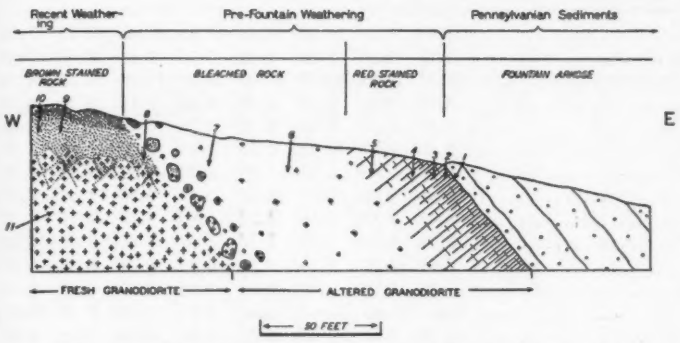

FIGURE 2.—*Cross section at right angles to Fountain-granodiorite contact* Flagstaff Mountain. Numbers and arrows indicate locations of specimens collected for analysis.

At some localities the Fountain rests on fresh rock. This should be expected, for the Fountain formation was derived from the same rocks as those on which it now rests, and erosion must have stripped the weathered rocks in many places, leaving basement rocks or only vestiges of the weathered mantle. There is no assurance that the uppermost part of the weathered mantle on Flagstaff Mountain has not been stripped away.

The altered granodiorite at the contact (Pl. 1, fig. 2) is a deep brownish red and is enriched in hematite and limonite. The brownish-red rock grades downward into a lighter-red rock not as rich in iron oxides. The red-stained horizon is about 30 feet thick. At the bottom of the red horizon the rock changes within a few feet into a light-gray or pinkish-gray, almost white, slightly mottled rock. The light-colored rock looks bleached and offers a decided color contrast to the medium-gray underlying fresh granodiorite. The bleached horizon is about 50 to 60 feet thick, and its base contains residual boulderlike masses of relatively fresh granodiorite. These masses are residual in the sense that the weathering near the bottom of the bleached material was guided by joint cracks, and the alteration was not so pervasive as it was closer to the surface. Thus, isolated rounded fresh boulders are separated by altered matrix.

Chemical characteristics.—The chemical changes as a result of pre-Fountain weathering were determined by several chemical analyses (Table 2). Uncombined silica was determined by the method outlined by Knopf (1933). The analysis of a biotite-rich schlieren in the granodiorite (No. 12) is included to show the composition of the least silicic portion of the fresh granodiorite mass found in field exposures.

Figure 3 shows the variation of the oxides in the analyses with depth in the pre-Fountain weathered rocks. In the red rock at the top, immediately beneath the

TABLE 2.—*Chemical analyses of granodiorite subjected to pre-Fountain weathering, Flagstaff Mountain, Boulder, Colorado*

Analyst: E. E. Wahlstrom

CHEMICAL ANALYSES

	1*	2	3	4	5	6	7	11	12
SiO_2	55.46	57.69	58.66	58.54	61.49	65.46	68.15	67.92	62.42
TiO_2	1.53	1.34	1.21	1.12	0.78	0.44	0.55	0.55	1.02
Al_2O_3	21.37	18.44	18.02	19.08	14.35	13.22	14.26	14.70	15.56
Fe_2O_3	8.65	6.85	6.55	6.46	4.65	2.79	2.24	0.91	1.47
FeO	0.37	1.04	0.82	0.44	0.78	0.74	1.03	2.61	3.82
CaO	0.38	0.76	0.58	0.83	1.75	2.04	1.17	2.94	4.25
MgO	0.56	2.71	1.69	2.01	2.18	1.31	1.19	0.98	2.87
Na_2O	0.49	0.54	0.57	0.61	0.42	0.53	1.95	3.31	3.59
K_2O	6.48	5.94	7.10	6.71	6.90	5.59	4.76	4.38	3.25
H_2O+	3.58	4.03	3.32	3.25	5.81	5.64	3.54	0.80	0.98
H_2O-	0.97	0.93	1.33	1.14	0.43	0.48	0.48	0.36	0.26
P_2O_5	0.20	0.32	0.29	0.38	0.24	0.13	0.12	0.18	0.34
CO_2	None	None	None	None	0.90	2.26	0.10	None	Trace
MnO	0.03	0.03	0.03	0.02	0.05	0.05	0.04	0.03	0.07
	100.07	100.62	100.17	100.59	100.73	100.68	99.58	99.67	99.90
Uncombined SiO_2	20	22	20	21	25	28	31	24	

ANALYSES MINUS WATER AND MINOR OXIDES

Sum calculated to 100%

SiO_2	58.3	60.7	61.5	61.2	65.9	71.1	71.3	68.2	63.4
TiO_2	1.6	1.4	1.3	1.1	0.8	0.4	0.6	0.6	1.0
Al_2O_3	22.4	19.3	19.0	20.0	15.3	14.5	15.0	15.0	15.9
Fe_2O_3	9.0	7.2	6.9	6.8	5.0	3.0	2.3	0.9	1.5
FeO	0.4	1.1	0.8	0.4	0.8	0.7	1.0	2.6	3.9
CaO	0.4	0.8	0.6	0.8	1.9	2.2	1.3	2.9	4.4
MgO	0.6	2.8	1.8	2.1	2.4	1.5	1.3	1.0	2.9
Na_2O	0.5	0.5	0.6	0.6	0.4	0.5	2.1	3.3	3.7
K_2O	6.8	6.2	7.5	7.0	7.5	6.1	5.1	4.5	3.3
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

* *See* Figure 2 for location of specimens.
Analyses 1–7 inclusive: altered granodiorite.
Analysis 11: fresh granodiorite.
Analysis 12: biotite-rich schlieren in granodiorite.

Fountain arkose, Fe_2O_3 and Al_2O_3 are at maxima, and SiO_2 and Na_2O are at minima. K_2O and H_2O reach maxima at the level of the bleached rock as does CO_2, although it is not shown in the graph. FeO is present in small amounts throughout the weathered material. The other oxides do not show significant variations.

Outstanding is the apparent enrichment of the upper portion of the weathered mantle in Fe_2O_3 and Al_2O_3 and the progressive desilication from the bottom of the mantle to its upper limit.

The iron oxide in the red-stained rock is residual. Proof that there has been little or no migration of iron oxide either upward or downward in the weathered mantle is found in altered pegmatite and aplite dikes in the red-stained weathered granodiorite. Weathering in the dikes is similar to that in the granodiorite but, in general, is not as pervasive because of the protective action of abundant quartz.

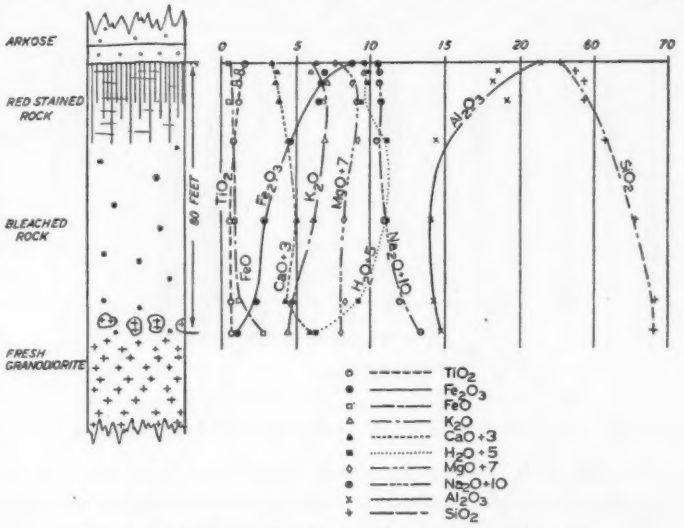

FIGURE 3.—*Variation of weight percentages of oxides with depth*
Pre-Fountain weathered mantle.

The red stain is not present in the dikes, although the decomposed, porous nature of the altered rocks in the dikes would permit easy ingress of iron-bearing solutions.

The analyses were plotted on a triangular diagram (Fig. 4) with SiO_2, $Fe_2O_3 + Al_2O_3$, and $CaO + Na_2O$ at its apices. These oxides were selected because they show particularly significant variations.

Two methods were used to recompute the analyses. In one method the total SiO_2 in the analysis was included. In the other method the uncombined SiO_2 (free quartz) was subtracted before the analysis was recomputed. Plots of the results of both methods of recomputation indicate the same trends from the bottom to the top of the zone—that is, systematic enrichment in $Fe_2O_3 + Al_2O_3$ and systematic impoverishment in $CaO + Na_2O$ and SiO_2. The plotted points for the analyses in which uncombined SiO_2 was excluded show that the extreme alteration of the granodiorite near the contact with the Fountain formation has resulted in a material close to the kaolinite stage of decomposition.

If erosion removed even a small part of the upper part of the pre-Fountain zone and the trends persisted, it is reasonable to assume that the altered rock at the original land surface was even richer in Fe_2O_3 and Al_2O_3 than the uppermost rocks still remaining.

Mineralogical characteristics.—X-ray and microscopic studies of the samples from the pre-Fountain weathered material yielded significant data. Heavy minerals were separated in bromoform and examined optically. The lighter fractions were studied before and after fine grinding and centrifuging. The X-ray technique was

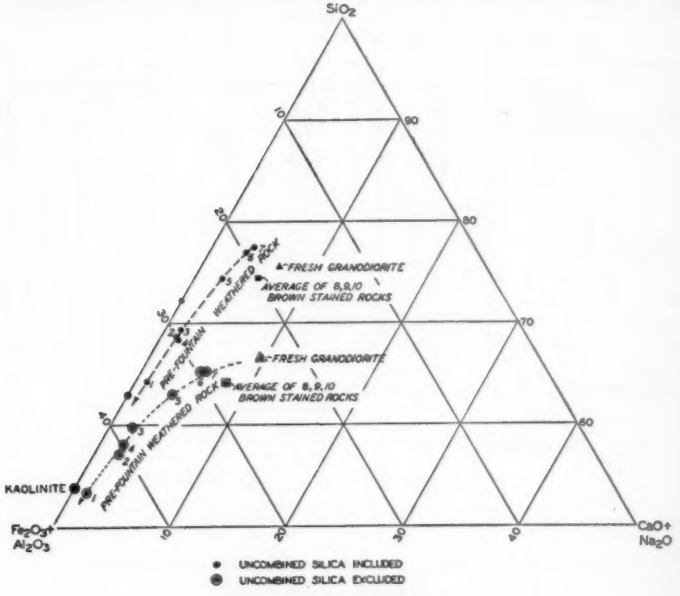

FIGURE 4.—*Triangular diagram*

Showing trends of chemical changes in pre-Fountain weathered mantle. Oxides plotted as weight percentages after computing sum to 100 per cent.

useful in identifying clay minerals in centrifuged portions of the light fractions. An effort was made to determine all significant systematic or nonsystematic mineralogical changes with depth.

Original minerals in the granodiorite are quartz, microcline, oligoclase, biotite, hornblende, and minor accessories. Secondary minerals resulting from pre-Fountain weathering are iron oxides, hydrated mica, clay minerals, and dolomite. Figure 5 shows the relative persistence of each of the abundant minerals and the variation in amounts of each individual mineral with depth.

Quartz, as would be expected, is resistant and persists throughout the weathered mantle. However, in the upper part of the mantle the quartz grains are somewhat rounded and embayed and show the effects of peripheral dissolution. The microcline reacted in much the same way as quartz. It is present in subrounded embayed fragments near the top of the mantle but in unaffected grains in deeper horizons. Although it has been corroded by the weathering solutions, it is as fresh in the most intensively altered portion of the granodiorite as in the original granodiorite. A few grains show a dust of clay minerals. Veins, generally parallel to cleavages and containing fine-grained silica and clay minerals, are present in some grains.

The oligoclase is one of the least stable minerals. It has been converted to clay minerals and fine-grained silica in samples extending to the very bottom of the altered mantle where the fresh granodiorite first shows the effects of pre-Fountain weathering. However, despite the extreme susceptibility of the oligoclase to weathering the

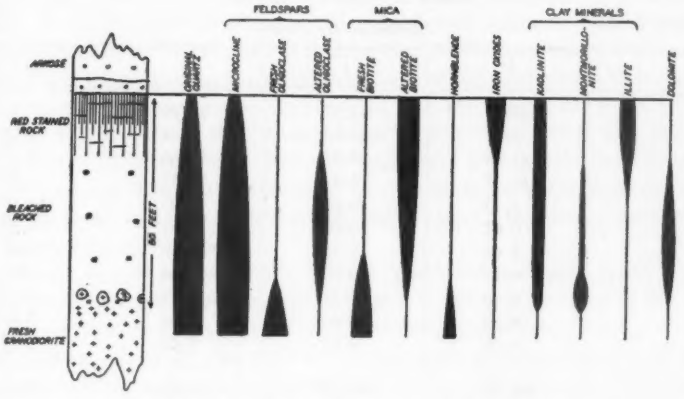

FIGURE 5.—*Diagram showing persistence with depth of important minerals in pre-Fountain mantle*

outlines of its grains can be identified almost all the way through the bleached horizon and up to the bottom of the red-stained horizon. The clay minerals resulting from the alteration of the oligoclase show a variable distribution with depth. At the bottom of the weathered mantle the oligoclase has been converted largely to kaolinite and montmorillonite. In the central and upper portions of the bleached horizon illite, kaolinite, and dolomite aggregates mark the position of altered oligoclase crystals. No vestige of oligoclase remains in the red-stained horizon.

Inasmuch as micaceous minerals persist in abundance throughout the weathered rock, the writer separated and analyzed micas from each horizon to determine how the chemical and optical properties vary with depth. For several reasons the results were of indifferent value. The biotite weathered erratically giving at any horizon in the weathered mantle plates with separate alternating layers of considerably different composition. Moreover, iron oxide resulting from decomposition was deposited unevenly in a very fine state of subdivision through the mica making it virtually impossible to obtain uncontaminated material for analysis.

Table 3 gives analyses and optical properties of the micas separated from selected samples. Considering only the bulk composition of the micaceous minerals, including the iron-oxide impurity, there is a progressive increase in the amounts of silica and alumina from the fresh granodiorite to the top of the weathered mantle, a progressive oxidation of the ferrous oxide to ferric oxide, and progressive leaching of lime, magnesia, and potash. Water is present in about the same amounts in all the altered micas.

In thin section it is seen that the separation of the iron oxide is most pronounced in the red-stained horizon. The red color is due to the release of notable amounts

of hematite by weathering of the mica. However, there is a suggestion that the mica has absorbed small amounts of iron oxide of extraneous origin.

All the altered micas swell when heated and give the physical reactions of vermiculite. When wet, the plates have the characteristic glitter of "fool's gold." How-

TABLE 3.—*Micaceous minerals*

CHEMICAL ANALYSES

	1*	4	6	11
SiO_2	43.09	42.37	40.29	38.14
TiO_2	2.67	2.13	2.48	2.51
Al_2O_3	21.83	19.33	16.66	14.93
Fe_2O_3	14.15	13.44	12.87	3.87
FeO	1.15	0.88	2.05	13.39
CaO	0.02	0.02	0.89	1.25
MgO	3.68	8.15	10.06	13.02
Na_2O	0.12	0.30	0.46	1.14
K_2O	6.90	7.18	7.73	8.37
H_2O	6.82	6.40	6.91	3.49
MnO	0.02	0.02	0.06	0.15
	100.45	100.22	100.46	100.26

OPTICAL PROPERTIES

	1*	4	6	11 (Fresh mica)
α	—	—	—	1.587 ±0.003
γ	1.613	1.615	1.615	1.621 ±0.003
2V	?	?	?	Practically zero
Pleochroism	Faint: Yellow and colorless	Faint: Yellow and colorless	Yellow and light brown	Light yellowish brown and olive green

* Numbers identify rocks from which mica was separated. *See* Figure 2 for location of specimens.
Analyses 1 and 4: red-stained zone.
Analysis 6: bleached zone.
Analysis 11: biotite from fresh granodiorite; contains about 2 per cent hornblende.

ever, the relatively low water content and the microscopic examination suggest that the micaceous mineral is "hydrobiotite" (Gruner, 1934). According to Gruner, hydrobiotite is a "molecular" interstratification of biotite and vermiculite.

The refractive indices could not be determined accurately in the altered biotite because of impurities and erratic alteration of individual layers in the mica plates. The average properties of the altered micas and the properties of the fresh biotite (No. 11) are listed in Table 3.

The photomicrographs (Pl. 2) show successive stages in the alteration of the biotite.

The hornblende altered easily, and it is not present a short distance above the bottom of the weathered mantle. However, its former presence is indicated by

aggregates of iron oxides, clay minerals, carbonate, and a micaceous substance. No trace of hornblende or its alteration products is found in the upper part of the bleached horizon or in the red-stained horizon.

X-ray examination of centrifuged portions of the lighter fraction of the altered rock shows that kaolinite is persistent throughout the weathered mass, montmorillonite is present only in the bleached horizon, and illite is abundant in the red-stained horizon. Intensive alteration in the red-stained rock seems to have favored the development of illite at the expense of both kaolinite and altered mica.

Dolomite is the only mineral that gives positive evidence of having been deposited from solutions. It is confined to the bleached rock and is generally found in altered aggregates resulting from the decomposition of oligoclase. It is also present in veinlets cutting other minerals. Several fragments of quartz and microcline contain intersecting cracks filled with pure dolomite. Probably the dolomite in the veinlets was derived from adjacent altered minerals and not from solutions moving downward from the original land surface.

The minor accessory minerals of the fresh granodiorite—chiefly apatite, sphene, magnetite, and allanite—are not visible in any of the thin sections of the altered rocks and presumably were altered or leached beyond recognition.

The order in which the minerals of the granodiorite decomposed is in general agreement with the order of decomposition given by Goldich (1938) in his mineral stability series.

Volume changes.—The rocks in the bleached horizon preserve the original texture of the granodiorite although they are much more porous than the fresh rock. In the red-stained horizon the leaching has been extreme. The minerals in the red horizon are chiefly illitic mica, hematite, quartz, and microcline; under the microscope, these minerals form a clastic mass resembling in many respects the overlying arkosic sediments of the Fountain formation. The micaceous material forms jumbled aggregates surrounding rounded and subrounded grains of quartz and microcline. The texture is the result of removal of large amounts of the original and secondary minerals by leaching with concomitant collapse and compaction of the residual material.

The exact amount of bulk volume change due to compaction could not be determined by any means available to the writer, because too many unknown factors must enter into any computation that might be made.

RECENT WEATHERING

Recent weathering has converted the fresh granodiorite into a loosely coherent, crumbly, brown-stained rock. This type of weathering is seen in exposed crystalline rocks over most of the foothills belt of the Front Range and is characteristic of the arid to semiarid climate that prevails over much of the region. Recent weathering has not affected the rocks in the pre-Fountain weathered mantle because the decomposition of these rocks has proceeded to a stage far beyond that resulting from recent weathering.

Recent weathering has stained the exposed residual boulders near the base of the pre-Fountain mantle a characteristic brown and in this respect has simulated an

effect similar to one in northern Colorado described by Thompson (1931) who found brown, limonite-stained residual granite boulders embedded in a light-gray to pinkish-gray altered rock below the Fountain formation. Thompson interpreted the brown alteration as the result of recent weathering acting on exposed residual boulders of fresh granite that originally were present near the base of a pre-Fountain regolith.

TABLE 4.—*Chemical analyses of rocks altered by recent weathering, Flagstaff Mountain, Boulder, Colorado*

Analyst: E. E. Wahlstrom

	8*	9	10	11
SiO_2	67.26	65.12	69.33	67.92
TiO_2	0.54	0.64	0.48	0.55
Al_2O_3	16.03	16.34	14.52	14.70
Fe_2O_3	2.48	2.64	2.33	0.91
FeO	1.00	1.77	0.95	2.61
CaO	1.61	2.32	1.61	2.94
MgO	0.74	1.30	0.27	0.98
Na_2O	3.38	3.03	2.94	3.31
K_2O	4.08	4.73	4.35	4.38
H_2O+	2.05	1.91	1.85	0.80
H_2O-	0.34	0.55	0.94	0.36
P_2O_5	0.16	0.22	0.16	0.18
CO_2	Trace	Trace	None	None
MnO	0.04	0.06	0.02	0.03
	99.71	100.63	99.75	99.67
Uncombined SiO_2	26	25	25	24

* *See* Figure 2 for location of specimens.
8, 9, 10: recently weathered granodiorite.
11: fresh granodiorite.

The recently weathered rocks are easily identified inasmuch as they are related to the present land surface. In contradistinction, the pre-Fountain weathered mantle parallels the contact between the granodiorite and the Fountain formation.

The chemical changes resulting from recent weathering of the granodiorite are shown in Table 4. Figure 6 shows the changes in the granodiorite produced by recent weathering. Average weight percentages of the oxides were computed from analyses 8, 9, and 10 and were plotted with the weight percentages of oxides in the fresh granodiorite. Despite the greatly changed appearance of the altered rock as compared to the fresh granodiorite, the chemical changes are not excessive. The most noteworthy change resulting from recent weathering is the oxidation of the ferrous oxide to ferric oxide and an increase of a few per cent in the total amounts of water and alumina.

Mineralogically, the chemical changes reflect the formation of silica, kaolinite, and small amounts of montmorillonite and illite at the expense of oligoclase, and an erratic oxidation of the iron in the biotite and hornblende resulting in more pronounced pleochroic colors and slightly higher refractive indices. Some of the biotite

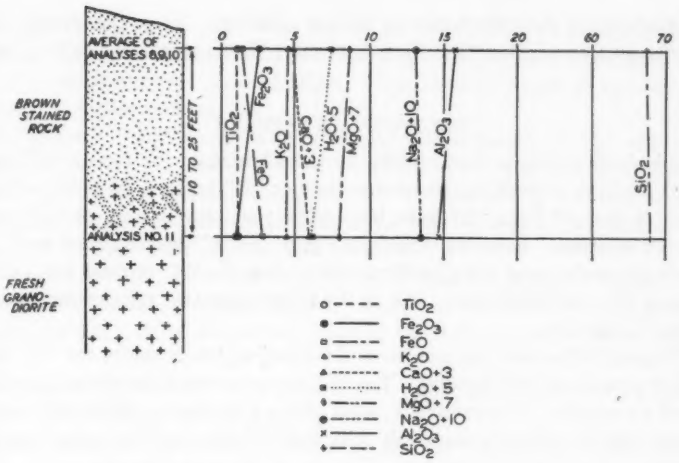

FIGURE 6.—*Diagram showing chemical changes in granodiorite*
Result of recent weathering. Oxides plotted in weight percentages.

TABLE 5.—*Biotite from recently weathered and fresh granodiorite*
Analyst: E. E. Wahlstrom

	9*	11	9	11
SiO_2.....	37.50	38.14	$\alpha = 1.592 \pm .003$	$\alpha = 1.587 \pm .003$
TiO_2.....	2.79	2.51		
Al_2O_3.....	14.14	14.93	$\gamma = 1.627 \pm .003$	$\gamma = 1.621 \pm .003$
Fe_2O_3.....	10.90	3.87		
FeO.....	7.86	13.39	2V = nearly zero	2V = nearly zero
CaO.....	2.56	1.25		
MgO.....	11.29	13.02	Pleochroism strong; dark greenish brown and yellowish brown	Pleochroism moderate; olive green and light yellowish brown
Na_2O.....	0.44	1.14		
K_2O.....	5.52	8.37		
H_2O.....	6.79	3.49		
MnO.....	0.20	0.15		
	99.99	100.26		

9: biotite from recently weathered granodiorite.
11: biotite from fresh granodiorite.

has been converted to vermiculite, as indicated by the chemical analyses and optical properties of biotite from recently altered and fresh granodiorite (Table 5). The degree of oxidation of the biotite and hornblende differs with local conditions and in some thin sections it is apparent that the limonite stain so conspicuous in field exposures of the altered granite has come from the oxidation and hydration of iron set free by the altered biotite and hornblende.

However, the presence of limonite in joint cracks and along contacts between grains of feldspar and quartz suggests that some or much of the limonite stain has

been introduced by downward-moving surface solutions. Thus the recently weathered rocks present evidence that there has been addition of iron oxides to the stained rocks.

PRE-FOUNTAIN CLIMATE

A typical soil profile is characterized by three horizons: the top or "A" horizon, in which leaching is evident; the intermediate or "B" horizon, to which substances presumably derived from "A" have been added; and the bottom or "C" horizon, the parent material. Some soil scientists regard the "C" zone as fresh rock, others regard it as consisting of the altered material below the "B" horizon and extending downward into unaltered rock. It is in the latter sense that the present writer uses the term "C" horizon.

On Flagstaff Mountain the pre-Fountain weathered rock shows the "C" horizon and all or part of the "B" horizon. The "A" zone appears to be absent, presumably removed by erosion. Unfortunately, most of the literature in which soil characteristics are related to climate deals only with the "A" zone and the upper part of the "B" zone.

According to Reiche (1945) three distinct associations of soil-forming processes depend on climate:

(1) Podsolization is normal for temperate humid climates and forest vegetation and results in concentration of iron or iron and aluminum in the "B" zone. Characteristic are acid soils in which silica removal and rather complete removal of alkalis and alkaline earths are noteworthy. Clay minerals are the normal end products of this type of weathering. Below the "A" zone the podsolic soils are brown to gray brown, grading into yellows and reds in their southern development where the influence of laterization is felt.

(2) Calcification results in accumulation of notable amounts of calcium and magnesium carbonates in the "B" horizon. It is distinguished by the presence of "caliche" at the depth of average penetration of surface water. Calcification is normal to dry climates and to areas characterized by brush or grass vegetation. The clay minerals may be bentonitic. The "C" zone of regions characterized by calcified soils is generally only a few feet thick.

(3) Laterization is characteristic of tropical weathering. The term "laterite" was originally applied to a material from the "B" zone in tropical humid regions. Containing an unusual concentration of iron and aluminum sesquioxides, laterite is typically brownish red or yellowish. Evidence for the removal of considerable silica is generally present. Laterites derived from silica-deficient source rocks may contain hydrated aluminum oxides. Laterites derived from siliceous source rocks generally contain abundant clay minerals, notably kaolinite. Tropical humid weathering commonly affects rocks to considerable depths.

Features in the pre-Fountain weathered mantle on Flagstaff Mountain that affect the interpretation of the climate at the time of the weathering are:

(1) A notable thickness of preserved weathered mantle—approximately 80 feet.

(2) A "C" zone about 50 feet thick grading upward into an iron-oxide-rich zone about 30 feet thick which may represent all or part of the "B" zone.

(3) Carbonates in the "C" zone which are interpreted as resulting from the weathering of ferromagnesian minerals and oligoclase in place, with some solution and redeposition near the point of origin. The dolomite probably was not derived from rocks in higher horizons.

(4) Chemical trends which show increasing concentration of iron oxides and a notable decrease in silica from the bottom of the weathered mantle to its present top. If the trends continued upward into a portion of the mantle removed by erosion prior to the deposition of the Fountain arkose the land surface prior to erosion locally may have exhibited an iron-oxide crust.

(5) Presence of abundant clay minerals with a characteristic distribution through the weathered mantle; montmorillonite is present near the base; illite is abundant in the iron-enriched rock; and kaolinite is abundant throughout the whole weathered mass.

(6) The sharp contrast in extent, color, and zonal characteristics when compared to the rocks altered by recent weathering.

Considering all factors, three conclusions emerge: (1) the climate was humid; (2) the average temperature was moderate to high; (3) if a different type of rock had been present, a typical laterite would have formed.

STRATIGRAPHIC RELATIONSHIPS

Some notion of the age of the pre-Fountain weathered mantle and the prevailing climate may be obtained by a study of the relationships of the basal sedimentary rocks along the east side of the Front Range. The Fountain formation of Pennsylvanian (Des Moines or post-Des Moines) age rests on the pre-Cambrian rocks for a distance of at least 70 miles north of Boulder as far as the Colorado-Wyoming State line where it has been identified as the lower part of the Casper formation. In northern Colorado near the State line the basal portion of the Fountain formation contains red-stained chert nodules containing Mississippian fossils derived from the Madison limestone. South of Boulder the Fountain arkose is the basal sedimentary formation at least as far as an unknown point between Deer Creek and Perry Park—a distance somewhere between 40 and 60 miles. At Perry Park the Fountain rests unconformably on beds at least as young as the Leadville limestone of Madison age.

The fossiliferous chert pebbles in the lower portion of the Fountain in northern Colorado apparently are residual in the sense that they were originally present in the Madison limestone and were left behind on the land surface after the erosion and solution of the limestone. The brownish-red color is the result of introduction of iron oxides into the pebbles as the limestone was being eroded, and while the pebbles lay exposed on the land surface. Chert pebbles in unweathered Madison are normally white to light gray. The red color was not introduced into the pebbles after incorporation into the Fountain formation because boulders of a variety of other rock materials in the Fountain have not been similarly affected. The red color is the same as that in the "B" zone of the weathered mantle on Flagstaff Mountain. The stratigraphic position of the chert pebbles and their characteristic coloration indicate that they were exposed to the same climatic and other conditions as the rocks beneath the Fountain contact on Flagstaff Mountain.

At Perry Park limestones beneath the unconformity at the base of the Fountain formation are red-stained to a depth of several feet. The amount of staining is a function of the distance below the unconformity and is most intense at and immediately below the unconformity. Moreover, small residual hematite deposits are common on the buried land surface that marks the unconformity and probably formed in the same manner as similar deposits of hematite in undisputed laterites in other parts of the world.

The above observations lead to the following conclusions: (1) The weathered mantle on Flagstaff Mountain is pre-Fountain and post-Madison; (2) it was formed while the unconformity between the Fountain arkose and Leadville limestone at Perry Park was in process of development; (3) the weathered rocks on Flagstaff Mountain stratigraphically are equivalent to laterized rocks elsewhere in the region.

The chert pebbles in northern Colorado indicate that Madison limestone was once present there or in immediately adjacent regions. Thompson (1931) found evidence for pre-Fountain weathering in a pinkish-white altered pre-Cambrian rock beneath the Fountain formation. The weathering Thompson describes probably was synchronous with that on Flagstaff Mountain and developed largely during and after the removal of the Madison limestone.

The evidence is clear that after the deposition of limestones of Madison age of the northern part of the Front Range was gently uplifted and a broad surface of low relief, but with sufficient drainage to permit deep weathering, was exposed to the corrosive action of the atmosphere and ground water. After a period of weathering, during which the Madison limestone and older formations were locally removed by erosion and a thick, reddish regolith was developed, the uplift was intensified, and the uplifted area began rapidly to shed the Fountain sediments. Some geologists refer to the uplift that lay slightly to the west of the present hogback exposures of the Fountain formation as the "ancestral Rockies."

Thus the red color of the Fountain formation is inherited from a pre-Fountain regolith which was conditioned by pre-Fountain and post-Madison weathering and was rendered susceptible to rapid denudation during and after uplift. The red color of the Lyons sandstone and the Lykins shales and sandstones which overlie the Fountain formation in the Boulder district probably has a similar ultimate origin. The climate was conducive to the development of laterite.

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SEDIMENTATION IN THE MIDDLE RIO GRANDE VALLEY, NEW MEXICO

BY STAFFORD C. HAPP

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ABSTRACT

Surveys have shown sediment accumulation at a rate of 12,000 acre-feet per year, or 22.5 million tons, from 1936 to 1941 in the Middle Rio Grande Valley of central New Mexico. Throughout most of the upper 133 miles of the Middle Valley, the Rio Grande is confined within a levee-bordered floodway, which was aggraded at a rate equivalent to 0.08 foot per year, or about 1 foot in 12 years. This was due to deposition on the berms between the levees and river, chiefly during major floods in 1937 and 1941, for there was practically no net change in average river-bed elevation through the floodway. The relation between berm and river-bed deposition is believed to be temporary, resulting from the scouring effect of a major flood shortly

before the 1941 surveys, for comparisons of water-surface elevations indicate river aggradation from 1917 to 1936 at about the same rate as the 1936–1941 floodway aggradation.

About 55 per cent of the 1936–1941 sedimentation was in the lower 14 miles of the valley, between the lower end of the floodway and the head of Elephant Butte Reservoir. This sediment concentration was due chiefly to headward growth of the reservoir delta, several channel avulsions that happened to occur during the short period of record, and perhaps some influence of the floodway levees in confining flood waters and forcing transportation of sediment into the lower part of the valley.

The sedimentation and river aggradation are serious problems affecting the future of irrigation, drainage, and flood-protection works essential for the productivity of more than 100,000 acres of agricultural land, and increasing flood hazards for about half the city of Albuquerque, many smaller communities, parts of a transcontinental railway and one of its major branches, and several major highways. The Middle Rio Grande may have been aggrading for centuries, but the rate of sedimentation is believed to have increased greatly since about 1870 as a result of arroyo erosion in the alluvial valleys of many intermittent tributaries. The arroyo erosion apparently was caused by depletion of the natural vegetation and trampling of trails by cattle and sheep. Some combination of detention reservoirs and channel improvements may provide temporary relief, perhaps for many years, but a successful long-term remedial program evidently will require stabilization of the eroding arroyos. Unfortunately it has not yet been demonstrated that effective measures for arroyo stabilization are practicable and economically feasible.

INTRODUCTION

The Middle Rio Grande Valley, in central New Mexico, extends about 150 miles from Cochiti, where the Rio Grande emerges from lava-walled White Rock Canyon west of Santa Fe, southward to San Marcial at the head of Elephant Butte Reservoir (Fig. 1). It includes several short narrow reaches but generally is an alluvial plain 2 to 5 miles wide, subject to occasional flooding except where protected by artificial levees or by highway, railway, or irrigation-ditch embankments. Irrigation has been practiced since prehistoric time, and most of the alluvial lands are now irrigated and farmed. The Middle Rio Grande Conservancy District, organized under State law, installed a comprehensive system of diversion dams, irrigation and drainage ditches, levees, and limited river-training works, through most of the valley between 1929 and 1933. Albuquerque, largest city in New Mexico, is partly in the alluvial plain, and Socorro, Belen, Los Lunas, and Bernalillo are the largest of many smaller towns. There are also several Pueblo Indian villages. Two main lines of the Santa Fe railway and two transcontinental highways cross the valley, and a branch rail line and through highway traverse most of its length.

Sedimentation has long been recognized as a serious problem, affecting the maintenance costs and even the future life of irrigation, drainage, and flood-protection works. Most of the sediment comes from erosion of arroyos in tributary valleys, but there has been little quantitative information concerning the rate and extent of river aggradation, and the relation to sedimentation in Elephant Butte Reservoir. To obtain reliable data as a basis for planning remedial measures, the Soil Conservation Service undertook a series of surveys and related studies in 1936 and continued them intermittently until 1942, largely under direct supervision of the writer.

ACKNOWLEDGMENTS

Earl H. Moser, Jr., was chief of the survey party in 1938 and 1941 and supervised most of the final office computations; the accuracy of the data is largely creditable to his ability and diligence. Louis M. Seavy was chief of the 1936 survey party, and Wilton F. Witzgall had a similar responsibility in 1937. Glen L. Anderson, Alvin T. Talley, and John Shearman were outstanding among many capable field assistants. Gordon Rittenhouse and Richard D. Grassey were responsible for most of the related laboratory studies, and Gene A. Zwerner supervised much of the office work. The investigation was begun under direction of Henry M. Eakin and continued under G. C. Dobson and Carl B. Brown, who aided the program in many ways, as did Arthur Fife, E. R. Smith, J. W. Jourdan, Herbert W. Yeo, M. E. Musgrave, and A. C. Blakey, all of the Soil Conservation Service. Special acknowledgment is due Herbert W. Yeo for much helpful advice and information, based on his long acquaintance with the Rio Grande and his energetic interest in the sedimentation studies. Many parts of the studies were based on information generously furnished by L. R. Fiock, O. J. Todd, and R. C. Lord, of the Bureau of Reclamation; L. M. Winsor and O. Dwight Cramer, of the Fish and Wildlife Service; R. H. Rupkey of the Office of Indian Affairs; Berkeley Johnson and Charles V. Theis of the U. S. Geological Survey; T. M. McClure, New Mexico State Engineer, and Willard C. Smith, Assistant State Engineer; Stanley Phillippi of the Middle Rio Grande Conservancy District; and T. A. Blair, E. H. Baltz, and F. C. Groman of the Atchison, Topeka, and Santa Fe Railway Company.

RATE OF SEDIMENTATION

A system of 90 cross-section lines, or "ranges," was adopted for measurement of the rates of sediment accumulation (Fig. 1). Wherever possible use was made of lines previously surveyed, which made the spacing erratic, but throughout most of the valley the ranges were about 3 miles apart. Generally the ranges were at closer intervals in the areas of most rapid sedimentation. Most of the ranges extend across the flood plain, but some were surveyed only between levees, and a few were limited to the width of the river channel at bridges. Twenty-eight of the range lines had previously been surveyed by the Bureau of Reclamation, A. T. & S. F. Railway, or Middle Rio Grande Conservancy District, and four were surveyed by the Fish and Wildlife Service about the time that the Soil Conservation Service surveys were begun. Each range was marked at either end, and usually also at the levees, by iron pipes set in concrete. Elevations for each range were established by leveling from U. S. Coast and Geodetic Survey or U. S. Geological Survey bench marks.

Most of the ranges cross the A. T. & S. F. Railway and are designated by numbers corresponding to their location, to the nearest tenth of a mile, relative to the mileposts. Range 868 is near Domingo, where the railway enters the upper part of the valley, and Range 1006.8(A) is at the head of Elephant Butte Reservoir, which is considered to be the lower end of the Middle Valley. Above Domingo there is no railway line for reference, and numbers have been assigned according to the

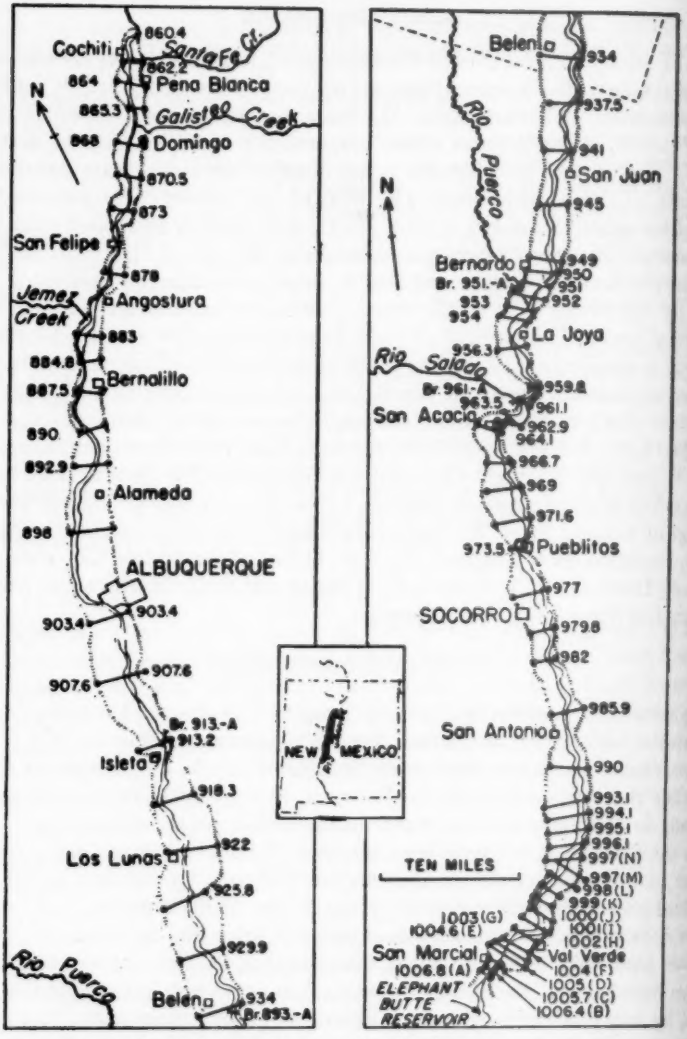

FIGURE 1.—*Map of Middle Rio Grande Valley, showing valley cross section ranges*
Ranges 913.1, 918, 926.5, 942.3, 997.2(0), 1001.8(1), 1002.4(2), and 1003.4(4) omitted for clarity.

distance above Range 868; the uppermost line is Range 860.4 near Cochiti, an Indian pueblo just below the mouth of White Rock canyon. Some of the ranges in the lower part of the valley had been designated by letters at the time of previous surveys by the Bureau of Reclamation, and these letters have been retained as suffixes, Range 1006.8(A) being the same as Range A of Bureau of Reclamation records. The ranges at railway bridges are designated by the bridge numbers,

TABLE 1.—DISTRIBUTION OF SEDIMENT DEPOSITED IN THE MIDDLE RIO GRANDE VALLEY, 1936-1941

Valley Segment		Interval between surveys	Floodway						Area of Sedimentation Outside Floodway				Entire Valley
			River		Outside River		Entire Floodway						
			Area	Volume	Area	Volume	Average Volume	Average Depth	Area	Volume	Average Volume	Average Depth	Average Volume
		Years	Acres	Ac.-ft.	Acres	Ac.-ft.	Ac.-ft./yr.	Ft./yr.	Acres	Ac.-ft.	Ac.-ft./yr.	Ft./yr.	Ac.-ft./yr.
Above 860.4		4.5	90	19	49	48	15	0.107					15
860.4	-864	4.5	405	172	731	123	66	0.057	296	101	22	0.076	88
864	-868	4.5	499	260	384	5	59	0.067					59
868	-878	4.8	840	-502	1/1433	1244	155	0.068	155	274	57	0.368	212
878	-883	4.8	575	302	2/1005	1167	306	0.194					306
883	-892.9	4.6	1021	600	1130	713	285	0.132					285
892.9	-898	4.8	903	631	403	310	196	0.150					196
898	-903.4	4.7	1273	256	367	146	86	0.052					86
903.4	-907.6	4.2	515	-294	314	54	-57	-0.069					-57
907.6	-913.2	4.6	835	-242	438	344	22	0.017					22
913.2	-918.3	4.9	795	-103	507	249	30	0.023					30
918.3	-925.8	5.0	1352	554	504	300	171	0.092					171
925.8	-929.9	4.6	686	89	255	316	88	0.094					88
929.9	-934	4.6	491	250	382	108	78	0.089					78
934	-937.5	4.7	524	440	291	-16	90	0.110					90
937.5	-941	4.7	458	46	293	330	80	0.107					80
941	-945	4.8	657	388	671	673	221	0.166	435	470	98	0.225	319
945	-949	4.6	757	340	505	291	137	0.109	2280	1813	394	0.173	531
949	-950	5.2	136	70	69	-15	11	0.052	724	538	103	0.143	114
950	-951	5.1	42	-68	446	288	43	0.088	438	401	79	0.180	122
951	-952	5.1	88	-158	253	226	13	0.039	240	78	15	0.064	28
952	-953	5.1	125	-218	142	34	-36	-0.135					-36
953	-956.3	5.1	987	-1836	558	847	-194	-0.126					-194
956.3	-959.8	5.1	610	-939	465	294	-126	-0.118					-126
959.8	-964	5.1	912	-705	536	645	-12	-0.008					-12
964	-969	4.9	995	-358	623	749	80	0.049	848	941	192	0.227	272
969	-973.5	4.9	1195	84	504	239	66	0.038	1533	1134	231	0.151	297
973.5	-977	4.5	747	-247	731	188	-13	-0.009					-13
977	-982	4.4	993	318	597	127	101	0.064					101
982	-985.9	4.4	645	71	814	877	215	0.148					215
985.9	-990	4.4	597	424	1843	2162	588	0.241	142	243	55	0.389	643
990	-993.1	5.0	616	1312	998	1416	548	0.338	2067	3721	744	0.360	1292
Subtotal to 993.1			21,364	956	18,241	14,482	3312	0.084	9158	9714	1990	0.217	5302
993.1	-997(N)	5.1	1362	4699	3599	6166	2130	0.429					2130
997(N)	-998(L)	4.9	330	1268	1113	3407	954	0.661	3/208	104	21	0.102	975
998(L)	-1000(J)	4.9	194	856	1468	4113	1014	0.610					1014
1000(J)	-1001(I)	5.0	90	448	868	2589	607	0.634					607
1001(I)	-1003(G)	5.0	239	-318	1311	4022	741	0.478	25	10	2	0.080	743
1003(G)	-1004(F)	4.9	75	-430	885	2542	431	0.448	84	20	4	0.051	435
1004(F)	-1004.6(E)	4.9	18	-134	625	1864	353	0.549					353
1004.6(E)	-1005(D)	4.9	24	-178	544	1706	312	0.549					312
1005(D)	-1005.7(C)	4.9	75	-482	429	1137	134	0.265	238	133	27	0.114	161
1005.7(C)	-1006.4(B)	4.9	31	-205	282	283	16	0.051	24	16	3	0.137	19
1006.4(B)	-1006.8(A)	4.9	14	-103	194	191	18	0.086					18
Subtotal (993.1-1006.8(A))			2452	5421	11,318	28,020	6710	0.487	579	283	57	0.098	6767
TOTAL			23,816	6377	29,559	42,502	10,022	0.188	9737	9997	2047	0.210	12,069

1/ Includes a considerable area unprotected by levees, on west side of river.
2/ Includes small area west of west levee, which cannot be separated in data for this period.
3/ Includes small area south of Range 998(L) and west of old railroad fill.

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which are in the same sequence as the mileposts except that they have alphabetical suffixes instead of decimal fractions. Bridge 893-A is an exception to the rule, as it is on a branch line crossing the Rio Grande between Ranges 934 and 937.5.

Resurveys were made between July 1941 and February 1942 on 47 ranges which had been surveyed in 1936 or 1937. Comparison of these surveys provide a cross-sectional measure of the sedimentation during periods varying from 4.2 to 5.1 years. These were converted to average annual rates to establish a uniform basis of comparison. Areas of sedimentation between ranges were measured by planimeter on maps compiled from aerial photographs. In most places the limits of deposition were known to coincide with levees, ditch banks, or other features shown on the maps, but where this was not the case, the limits were traced in the field after the 1937 and 1941 floods, the only extensive overflows during the period of study.

The amount of sediment in each valley segment, between adjacent ranges, was computed by the formula:

$$V = \frac{E_1 + E_2}{W_1 + W_2} + D_1 + D_2 \times \frac{A}{3}$$

in which

V = volume of sediment, in acre-feet;
E_1 and E_2 = cross-sectional areas of sediment at the bounding ranges, in square feet;
W_1 and W_2 = widths of the areas of sedimentation at the bounding ranges, in feet;
D_1 and D_2 = average depths of sediment at the bounding ranges, in feet; and
A = surface area of sedimentation between the bounding ranges, in acres.

The average annual sediment accumulation for 1936–1941 (Table 1) was approximately 12,000 acre-feet per year. The computations were carried to fractions of a foot in average depth, and to the nearest acre-foot in volume, for convenience in checking, but no such accuracy of detail is claimed. The volumes computed for individual segments, based on only two cross sections, are obviously subject to considerable error. The errors should be partly compensatory, however, so that the totals for any major part of the valley should be more reliable. The rate computed for the entire Middle Valley is believed to be sufficiently accurate for all practical purposes.

Only about a quarter of the valley received measurable deposits during the 1936–1941 period, chiefly because overflows were limited by the levees or, in a few places, by railway or highway embankments or by raised irrigation ditches. About 3300 acre-feet per year, or 27 per cent of the total accumulation, was deposited in the levee-confined floodway; about 2000 acre-feet or 17 per cent was left on parts of the flood plain behind the levees but overflowed because of levee breaks during the 1937 or 1941 floods. About 6700 acre-feet or 55 per cent of the total was concentrated in the lower 14 miles of the Middle Valley between the lower end of the floodway levees and the head of Elephant Butte Reservoir.

SEDIMENT CONCENTRATION AT THE HEAD OF ELEPHANT BUTTE RESERVOIR

The concentration of more than half the 1936–1941 sediment in the lower 14 miles of the valley was probably due chiefly to the effect of Elephant Butte Reservoir.

Sedimentation and river-bed aggradation obviously have been rapid in this area since 1914, the period of reservoir influence, and the former irrigated lands had been so badly damaged by previous floods and rising ground-water levels that adequate levees were not maintained and the 1937 and 1941 floods inundated practically all of this section (Pl. 2, figs. 1, 3). Several partial channel avulsions occurred during these floods, increasing the duration of overflows and causing much additional deposition of bedload sand (Pl. 1, fig. 2). These conditions were due mainly to the effects of past headward growth of the reservoir delta. The river was probably being aggraded more slowly prior to reservoir construction, however, and in later years the sedimentation in this section has probably also been increased by a tendency of the Conservancy District levees to confine sediment-carrying flood waters and thus induce transportation of more of the sediment into the area below the floodway.

The delta at the head of Elephant Butte Reservoir (Pl. 1) is large and conspicuous but wide fluctuations in river discharge and reservoir level have given it a complex form, and its limits are not clearly defined. It is largely overgrown with dense thickets of willows, cottonwoods, and salt cedar (tamarisk) and is gradationally continuous with the normal alluvial flood plain. The river flows through most of the delta without being obviously affected by the reservoir, except during the occasional periods of high reservoir stage. Much of the sedimentation in the delta area has taken place by the usual alluvial processes which would have prevailed without the reservoir, and there is no sharp distinction between deposits induced directly by retarded velocities at the head of the reservoir, which may be called "true" delta deposits, and alluvial deposition within the area of delta influence but perhaps not strictly of deltaic origin.

The extent of the Elephant Butte delta influence is probably shown by a general decrease in the 1936–1941 rates of sedimentation from the vicinity of Range 1001(I) upstream to Range 990, beyond which conditions were variable. Below Range 1001(I) maximum aggradation occurred prior to 1936, and channel degradation following avulsions reduced the 1936–1941 rate of net accumulation. Records of Bureau of Reclamation surveys show that the thickest deposition occurred in the vicinity of Ranges 1006.4(B) and 1005(D) during the period 1914–1936, but for the 1936–1941 period the thickest accumulations were in the vicinity of Ranges 1001(I) and 1000(J). Chance relations between the location of ranges and channel changes influence the data for individual ranges, but apparently the zone of thickest accumulation has migrated upstream at a rate of about a quarter of a mile per year.

The records of older surveys show a general increase in the rates of sedimentation. In the lowermost 2½ miles of the valley between Ranges 1004.6(E) and 1006.8(A), computations based on Bureau of Reclamation surveys show average accumulation of 234 acre-feet per year from 1914 to 1926, 398 acre-feet per year from 1926 to 1936, and the 1936–1941 rate was 507 acre-feet per year. In the next 4½ miles upstream, between Ranges 1004.6(E) and 1000(J), the records show a rate of 577 acre-feet per year from 1926 to 1936, and the 1936–1941 rate was 2137 acre-feet annually. There are no similar cross-section records prior to 1936 for the reach between Ranges 1000(J) and 990, but similar or greater increase in the sedimentation rate in this reach

FIGURE 1. DELTA AT HEAD OF ELEPHANT BUTTE RESERVOIR, DURING EARLY STAGE OF 1941 RIO GRANDE FLOOD

This is several miles below the head of the Reservoir, and about 35 miles from the dam which is out of sight in the background. Dense vegetation on unsubmerged part of delta is chiefly salt cedar (tamarisk) and young cottonwoods.

FIGURE 2. OLD AND NEW RIO GRANDE CHANNELS NEAR VAL VERDE

Just above Elephant Butte Reservoir, during 1941 flood. Most of the flow is in the new channel along the left margin of the flood plain, but later in 1941 the river reverted to the old channel where the two are closest (near center of view). Scattered cottonwood seedlings had grown on the sand of the old channel bed, after its partial abandonment during the 1937 flood. The site of former San Marcial, abandoned after being flooded and partly buried by sediment in 1929, is barely discernible among dark vegetation on the right bank beyond center of view, and the head of the Reservoir is hidden by lava-capped Black Mesa in background.

DELTA AND CHANNEL AVULSION NEAR HEAD OF ELEPHANT BUTTE RESERVOIR DURING 1941 FLOOD

FIGURE 1. FINE SAND DEPOSITS, SEVERAL FEET THICK, IN 1941 TEMPORARY AVULSION CHANNEL ALONG EAST SIDE OF FLOOD PLAIN, NEAR VAL VERDE
This was irrigated crop land prior to the 1937 flood, when overflow channel was first formed here.

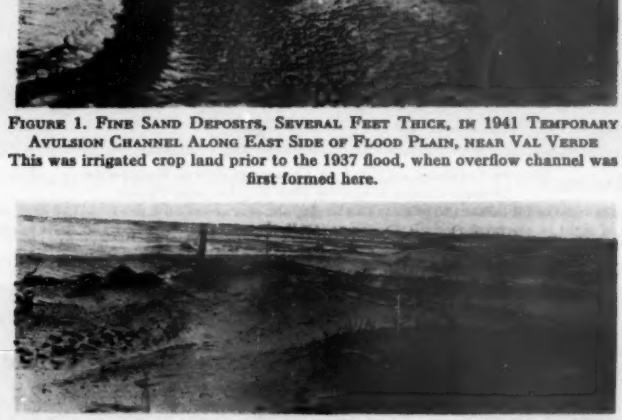

FIGURE 2. LOW, BARREN SAND DUNES DEVELOPED IN 1938 ON SEDIMENT DEPOSITED BY 1937 FLOOD, NEAR BERNARDO
This was grassy pasture land in 1936, but by 1941, when it was again overflowed, it was covered by a dense growth of salt cedar and cottonwood seedlings, standing 6 feet high.

FIGURE 3. SILT AND CLAY DEPOSITS, GENERALLY 1 TO 2 FEET THICK
Exposed by receding flood waters along San Marcial-Val Verde road in 1937.

TYPICAL FLOOD PLAIN SEDIMENT

is suggested by comparison of 1936 cross-section elevations with 1917–1918 topographic maps of the State Engineer's Office.

The total volume of 1936–1941 sedimentation below the floodway was about 6700 acre-feet per year, or about 55 per cent of all the Middle Valley accumulation. Not all of this, and perhaps not even the greatest part, was strictly deltaic deposition, but apparently it was all within the area of delta influence. If this be correct, the delta influence has progressed up valley at a rate of about half a mile per year and has already affected the lower end of the floodway. Normally the headward extension of this influence would be progressively slower, due to the increasing area of deltaic deposition, but the levees introduce an artificial factor not readily evaluated. The future headward extension of the delta influence, therefore, may be either more or less rapid, depending on the effect of the levees. This is a factor that should receive particular attention in further investigations. If the levees, and the comparatively minor amount of channel-training works maintained in connection with them, can check the headward extension of delta growth, the possibility of effective and practical engineering amelioration of the sediment problem throughout the Middle Valley is much greater. On the other hand, if the delta influence extends headward more rapidly within the restricted floodway, then a more extensive system of remedial works will be necessary for local protection.

AVULSIONS AND LOCAL CHANNEL DEGRADATION

There were several partial channel avulsions between the lower end of the floodway and the head of the reservoir during the 1937 spring flood (Pl. 1, fig. 2). Water from several east-side avulsion channels returned to the main channel where this impinges against the slopes of lava-capped Black Mesa, near Range 1005.7(C), and notable degradation of the channel bed began in this vicinity. Within a few months the main channel was deepened several feet for several miles in either direction. The upper limit was near Range 1003(G) where there was a concentrated return flow to the channel from overflow waters on the west side. Successive surveys showed that the deepening was gradual rather than by headward retreat of a single abrupt overfall or knickpoint, indicating that it was probably due to cutting off the bed-sediment supply by deposition upstream where the water was spread widely among the dense flood-plain thickets of willows and salt cedar.

There were no large floods, and the channel remained relatively unchanged from 1938–1940, but degradation was accelerated again during the major flood of 1941. During this flood part of the east-side overflow returned to the old channel near Range 1002(H) (Pl. 1, fig. 2). Channel degradation had extended up to this point by the end of 1941, and several miles of the old main channel had been deepened 5 to 8 feet and were only slightly above the river-bed elevations of 1914, prior to the reservoir influence. The channel capacity had been so increased that there was practically no overflow or overbank sedimentation in 1941 between Ranges 1005.7(C) and 1006.8(A).

The new channels formed by avulsions were underlain by cohesive silt and clay strata, generally about 10 feet thick in the area below the floodway, deposited from

former overflows but finer-textured than the avulsion deposits because deposited from quieter waters. These silt and clay strata are more resistant to stream erosion than the loose sands of the old channel bed, or those which underlie the superficial flood-plain deposits, and the new channels were not deepened as rapidly as was the part of the old channel below the avulsions. The new channels were deepened most rapidly where underlying sands were accessible, as where the new channels returned to the former course, or where existing ditches provided relatively easy access to the underlying sands. In such places overfalls soon developed by plunge-pool excavation of the sands under the silt and clay strata, which formed a resistant lip. Several short sections of the new channels were deepened 5 to 10 feet or more, from 1937 to 1941, by headward retreat of such overfalls on the east side of the main channel between Ranges 997(N) and 1005.7(C), but these deep sections were not integrated to form a continuous new channel around the avulsion area. The largest overfalls formed where the waters returned to the old channel from the east side near Ranges 1005.7(C) and 1002(H), but neither of these had retreated more than a few hundred feet by the end of 1941. Eventually a continuous and relatively deep new channel will probably be formed in this way around the zone of greatest aggradation of the old channel, and most of the sand load will again reach and aggrade the section of old channel which was degraded from 1937 to 1941.

RECORDS OF RIVER AGGRADATION BEFORE RESERVOIR CONSTRUCTION

Delta formation at the head of Elephant Butte Reservoir has accelerated sedimentation in the lower part of the Middle Valley, but there is evidence that river aggradation began here prior to construction of the reservoir and hence was initiated by other factors.

Santa Fe Railway Bridge 1005-A formerly spanned the Rio Grande near what is now the head of the Reservoir, until a channel change led to its abandonment in 1924. Records of cross-section surveys at this bridge show that the river bed rose about 3.6 feet from 1904 to 1912, and about 5.8 feet from 1912 to 1924. Several surveys at intervening dates show that aggradation was progressive throughout this period. Reservoir storage began January 1, 1915, yet the average rate of aggradation for the 1912–1924 period was only slightly, and certainly not significantly, greater than for the earlier period when there was no reservoir influence.

For the period prior to 1904, no records have been found of detailed cross sections at Bridge 1005-A, but comparisons can be made with the less precise 1880 construction profile. That profile shows the river channel about 350 feet wide with an average bottom elevation of about 4450 feet and an average elevation of about 4451.7 for a width of 500 feet corresponding to the width beneath the bridge in 1904. The detailed cross section of 1904 shows an average elevation of 4452.9 for a river channel 500 feet wide, indicating aggradation of 1 to 3 feet according to the width used for comparison; this suggests that sediment accumulation was probably less rapid before 1904. The change from 1880 to 1904, however, was not sufficient to prove general aggradation during that period.

Records of stream-discharge measurements near San Marcial, beginning in 1897,

also show river aggradation prior to reservoir construction. Interpretation of these records requires consideration of changes in the bed configuration as well as gage heights, which introduces a factor of uncertainty, but this does not seriously affect the general trend over a period of many years, for the stream bed does not change

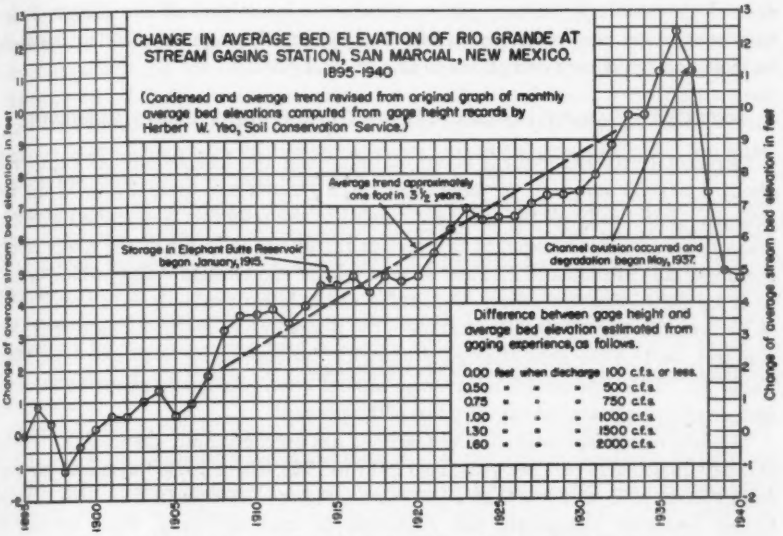
CHANGE IN AVERAGE BED ELEVATION OF RIO GRANDE AT STREAM GAGING STATION, SAN MARCIAL, NEW MEXICO. 1895-1940
(Condensed and average trend revised from original graph of monthly average bed elevations computed from gage height records by Herbert W. Yeo, Soil Conservation Service.)
Average trend approximately one foot in 3½ years.
Storage in Elephant Butte Reservoir began January, 1915.
Channel avulsion occurred and degradation began May, 1937.
Difference between gage height and average bed elevation estimated from gaging experience, as follows.
0.00 feet when discharge 100 c.f.s. or less.
0.50 " " " 500 c.f.s.
0.75 " " " 750 c.f.s.
1.00 " " " 1000 c.f.s.
1.30 " " " 1500 c.f.s.
1.60 " " " 2000 c.f.s.
Change of average stream bed elevation in feet
1895
1900
1905
1910
1915
1920
1925
1930
1935
1940

FIGURE 2.—*Change in average bed elevation of the Rio Grande at San Marcial*

greatly during the low stages which prevail for about 9 months out of most years. Herbert W. Yeo has computed the changing stage-discharge relation, using ratios of average depth to stage height based on his observations over a period of several years. These ratios might be considerably in error during the highest stages, but these affect only a small part of the record, which has been computed and plotted by Mr. Yeo on a monthly-average basis. The record has been further condensed by plotting only average yearly elevations in Figure 2. The graph shows that the rate of aggradation averaged about 1 foot per 3½ years from 1906 to 1936, or possibly for the entire period from 1897 to 1936. The early part of the record, prior to 1906, cannot be interpreted with certainty because of doubt as to whether the curve was near a high or a low point when the record began in 1897. Possibly there was an abrupt upturn in the rate about 1906, but this is not certain.

From the evidence of the bridge sections and the gaging records, it appears that much of the sediment deposited, between the reservoir and the floodway, during the period of records, probably would have been deposited there even if the reservoir had not been in existence. It might be inferred, from the same evidence, that the reservoir has had no important influence on the sedimentation; but more probably the reservoir influence is obscured because of other variables and the comparatively brief periods it has been directly effective. The reservoir has never been close to full stage

except in 1920 and 1941, so its backwater effect has been rather remote from the San Marcial area most of the time. The general upstream decrease in aggradation rates seemingly reflects the reservoir influence approximately up to the lower end of the Conservancy District floodway, but the full magnitude of the aggradation resulting from this influence has not yet extended upstream into the Middle Valley as here defined. Accordingly, sedimentation rates in the lower part of the Middle Valley may be expected to increase, perhaps for many years, although there will undoubtedly be local and temporary exceptions to this general rule.

EFFECT OF VALLEY SEDIMENTATION ON ELEPHANT BUTTE RESERVOIR

Elephant Butte Reservoir is about 40 miles long and had an original capacity of about 2,600,000 acre-feet, or more than twice the average annual flow of the Rio Grande. Practically all the sediment carried to the reservoir is deposited within it, and sedimentation is recognized as a serious threat to the future of the reservoir and the important Mesilla and El Paso sections of the Rio Grande valley, which depend on it for their irrigation water. According to the latest available data from Bureau of Reclamation surveys, sedimentation in the reservoir had reached a total of 415,800 acre-feet, or 15.8 per cent of original capacity, by September 1940 (Stevens, 1945, Table 1). This represented an average annual accumulation of about 16,200 acre-feet, or an average annual capacity loss of 0.6 per cent.

The rate of sedimentation in the reservoir has been generally decreasing. It was possibly 25,000 acre-feet per year from 1915 to 1920, about 15,000 acre-feet per year from 1920 to 1935, and less than 10,000 acre-feet per year from 1935 to 1940. These figures probably exaggerate the reduction in rate of filling, both because of unmeasured deposition between the date of original surveys, varying from 1907 to 1912, and the beginning of storage January 1, 1915, and because of compaction of the earlier deposited sediment. The former factor tends to make the reported rate too high during the first part of the period, and the latter tends to make it too low during the later years. The most important factor, however, probably has been headward growth of the delta beyond the original limit of the reservoir. As the delta grows, an increasing proportion of the sediment is deposited above crest elevation; hence the rate of capacity loss would decrease, even if the rate of sediment accumulation were unchanged.

It is believed that the delta influence extended upstream to the lower end of the Conservancy District floodway by 1941. In any case, all sediment deposited in this part of the valley area is thereby kept out of the reservoir, at least for a time, and hence reduces the rate of reservoir capacity loss. Furthermore, if other factors remain unchanged, a decreasing rate of capacity loss in the reservoir should continue because of the increasing proportion of the sediment deposited in the valley above the reservoir. Comparison of the proportional distribution of sediment in the reservoir and in the lower part of the Middle Valley is, therefore, a reasonable basis for estimating the effect of valley sedimentation on the future life of the reservoir.

To establish a common basis of comparison, it is necessary to convert the volumes of sediment, as measured by surveys, into equivalent weights, for there are large dif-

ferences in the specific weights of valley and reservoir deposits. In 1941 representative samples of Middle Valley sediments were collected for this purpose, and an average specific weight of 86 pounds per cubic foot or 1873 tons per acre-foot was derived (Happ, 1944). On this basis, the 6700 acre-feet of 1936–1941 deposits between the floodway and the reservoir were equivalent to about 12.5 million tons per year.

Comparisons based on older survey records covering part of the valley between the floodway and the reservoir, described in a preceding section, suggest that the rate of sedimentation during the 1936–1941 period was about 2½ times as great as during the 1914–1936 period. This would indicate a 1914–1936 rate of about 5 million tons per year. The deposition within the original reservoir area, but above reservoir crest elevation, is not included in the figures for either part of the deposits, but is too small to affect the comparison significantly (Happ, 1944, p. 18).

The rates of reservoir sedimentation, according to estimates based on an assumed average specific weight of 65 pounds per cubic foot, were about 27 million tons annually from 1915 to 1935, and about 13.5 million tons annually from 1935 to 1940 (Stevens, 1945). The difference of 1 year in the periods of reservoir and valley surveys, 1935–1940 and 1936–1941, does not appear to be a serious objection to their comparison, for the suspended load measured at San Marcial, according to International Boundary Commission determinations, was about 11 million tons per year for both periods.

These data indicate that, during the 1915–1935 period, the reservoir received about 85 per cent of the sediment passing the lower end of the present floodway, but during the 1936–1940 period only about 52 per cent of this sediment reached the reservoir. This great change was due largely to the river avulsions, but they in turn were the product of a long-continuing process of aggradation. Delta growth was only one of several factors contributing to the river aggradation, but further delta growth will doubtless cause such conditions to recur, more and more frequently in the future. The channel avulsions were normal alluvial processes, and, although they will not be equally effective at all times, they probably will recur with increasing frequency as the delta grows. The proportion of sediment carried into the reservoir thus will probably decrease, and the proportion deposited in the lower part of the Middle Valley will probably increase. The proportional increase in the delta sedimentation may be used as a guide to future trends in the distribution of sediment.

Figure 3 illustrates the effect of delta growth on the future rate of reservoir filling, the 1914–1935 and 1936–1940 rates of reservoir capacity loss being plotted as functions of the combined total of reservoir and valley delta deposition. Projection of a smooth curve through points representing the average values for the two periods leads to an estimate that the reservoir will be half filled in about 85 years from the present, which is probably as far into the future as the data justify prediction. This indicates a remaining reservoir life about twice as long as a straight-line projection of past rates (Stevens, 1945, Fig. 3). Neither the accuracy nor extent of present data, nor the certainty of future influences, is sufficient to justify any claims for high order of accuracy in any such estimates of the future sedimentation, but they show the importance of the delta sedimentation as a factor in the life of the reservoir.

Obviously channel-training or sediment-control works in the lower part of the

valley could not solve the problems alone, for improvement of flood and drainage conditions there would induce greater sedimentation in the reservoir, whereas local works for reservoir protection would induce greater aggradation in the valley.

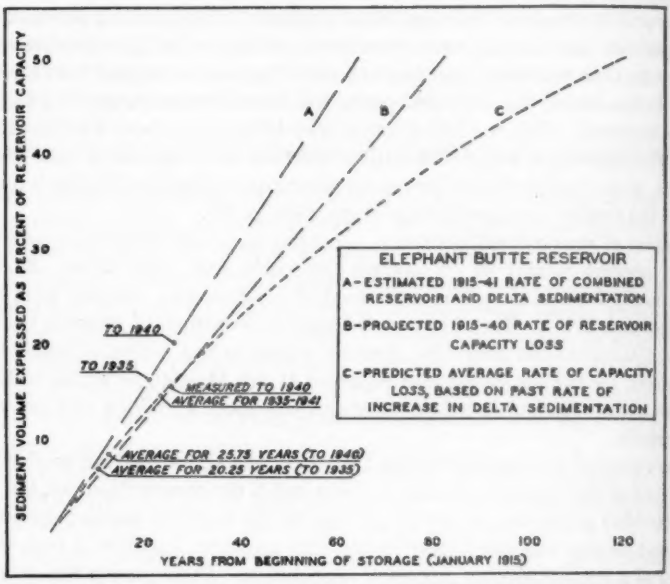

FIGURE 3.—*Projected rates of Elephant Butte Reservoir and delta sedimentation*

SEDIMENTATION IN THE CONSERVANCY DISTRICT FLOODWAY

Levees of the Middle Rio Grande Conservancy District now confine most flood waters to a relatively narrow floodway, generally a quarter of a mile to half a mile wide, throughout most of the valley above Range 993.1. This restriction of the overbank flows should tend to increase discharge velocities, but the surveys show it has not been sufficient to prevent aggradation throughout most of the floodway. The data vary considerably for different ranges, and in a few places there was net degradation from 1936 to 1941, but the evidence of a general condition of aggradation is convincing. Computations based on the cross-section surveys indicate accumulation at a rate equivalent to 3312 acre-feet per year for the 1936–1941 period, or aggradation of about 0.08 foot per year or 1 foot in 12 years (Table 1).

For the river channel alone there was a net average accumulation of about 252 acre-feet per year, equivalent to 1 foot in about 70 years, due almost entirely to deposition in the lower few miles of the floodway. This figure indicates essentially no change in the average river-bed elevation for the period 1936–1941. Thus the floodway aggradation was due to sedimentation on the berms between the river and the levees, but it does not necessarily follow that such relations are to be expected in

the future or as a long-term average. The disparity between rates of river and floodway aggradation is probably exaggerated because the 1941 surveys were made shortly after a major spring flood, which caused considerable local, and presumably temporary, channel scouring, and correspondingly large deposition on the berms.

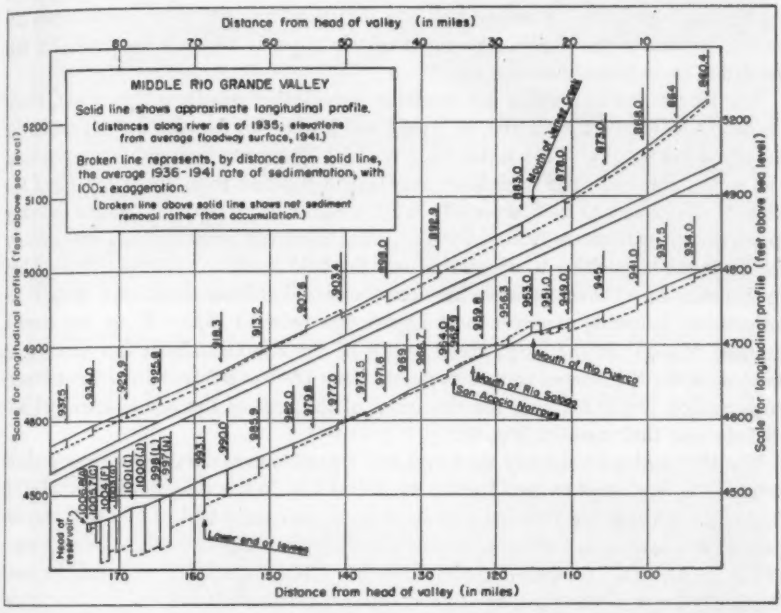
Distance from head of valley (in miles)
MIDDLE RIO GRANDE VALLEY
Solid line shows approximate longitudinal profile.
(distances along river as of 1935; elevations from average floodway surface, 1941.)
Broken line represents, by distance from solid line, the average 1936-1941 rate of sedimentation, with 100x exaggeration.
(broken line above solid line shows net sediment removal rather than accumulation.)
Scale for longitudinal profile (feet above sea level)
Mouth of Rio Puerco
Mouth of Rio Salado
San Acacia Narrows
Lower end of levee
Head of reservoir

FIGURE 4.—*Graphic representation of the 1936–1941 rates of floodway aggradation in the Middle Rio Grande Valley*

The tendency toward river-bed aggradation during periods of low flow or small floods, and of degradation by major floods, has been clearly shown by successive cross-section records for various parts of the valley, and for various parts of the 1936–1941 period. The data are insufficient for a reliable measure of the magnitude of these changes throughout the valley, but they suggest that the 1941 spring flood scoured about as much sediment from the river bed as had accumulated during the low flow years 1938–1940, except near the lower end of the valley. The 1941 deposition on the floodway berms, however, greatly exceeded the 1941 scouring of the river bed, so that net floodway aggradation continued even during 1941. These relations are well demonstrated above Albuquerque and are supported also by less complete data below Albuquerque.

For only three reaches, two of them quite short, the data indicate exceptions to general floodway aggradation for the period 1936–1941. In one of these, between Ranges 973.5 and 977 a short distance above Socorro, local bank erosion at one of the bounding ranges was a major factor in the indicated small net floodway degradation.

In a slightly longer reach between Ranges 903.4 and 907.6, extending downstream from Albuquerque, where three cross sections all show degradation, this may be due to a relatively wide river channel with correspondingly narrow floodway berms, and to the fact that the 1941 surveys here were made at relatively high stages when river-bed scouring was comparatively active. The local channel degradation in this reach undoubtedly helped mitigate 1941 flood hazards in the most highly improved section of the valley, but unfortunately there is no basis for expecting this condition to be more than temporary.

The longest reach showing net floodway degradation was from Range 952, a mile above the mouth of Rio Puerco, to Range 964 in the San Acacia narrows below the mouth of Rio Salado. Part of this is a gorge with little room for overbank deposition, and in the remainder the thick local overbank deposition from Rio Puerco and Rio Salado floods prior to 1936, especially in 1929, had built up the banks higher than any floods occurring between 1936 and 1941. Thus there was practically no opportunity for overbank deposition to counterbalance the 1941 flood scouring of the river bed in this section. The degradation here may be considered essentially as a delayed readjustment following excessive local aggradation prior to 1936. There has been a marked "hump" in the longitudinal profile of the Rio Grande in this vicinity, at least since the 1918 mapping, and probably since 1880 as inferred from the railway-construction profile showing the elevations of the beds of the Rio Puerco and Rio Salado near their mouths (Fig. 4).

The 1937 spring flood broke the levees and deposited considerable sediment on land west of the floodway between Ranges 942.3 and 952, in the vicinity of Bernardo (Pl. 2, fig. 2). During the 1941 flood the west levee was again broken and sediment deposited in this area, as well as on the east side of the floodway between the same ranges (Pl. 3, fig. 1), and there were other levee breaks and deposits on the west side between Ranges 964 and 973.5 (Pl. 3, fig. 2), and between Ranges 990 and 993.1. The aggregate volume of these deposits outside the floodway was about 9700 acre-feet, covering nearly 9200 acres. This would be equivalent to about 2000 acre-feet per year if distributed over the period 1936–1941, or nearly 40 per cent of the sediment above Range 993.1, although covering less than 20 per cent of the area of sedimentation.

If these breaks had not occurred in the levees, the average rate of floodway aggradation would probably have been appreciably higher, and it is evident that the river is capable of relieving itself of a considerable part of its sediment load by such temporary overflows. This is an important factor in the sedimentary regime.

Comparison can be made with four cross-section surveys of 1927 from Range 903.4 at Albuquerque to Range 925.8 about 3 miles below Los Lunas. During the period 1927–1936 the railway embankment, irrigation ditch banks, local levees, and the configuration of the valley sides had restricted overflows to about the same area as the present floodway. For this section of the floodway, the average accumulation was 204 acre-feet per year for the period 1927–1936, and 231 acre-feet per year for the period 1936–1941, the latter including the degradation in the immediate vicinity of Albuquerque. These comparative figures indicate no essential change in sedimentation rates in this part of the valley, for the computed net difference is insignificant. There are also records of 1927 and 1928 surveys for several ranges from the mouth of

FIGURE 1. 1941 FLOODING ON BOTH SIDES OF FLOODWAY LEVEES

Upstream from mouth of Rio Puerco which joins Rio Grande in the foreground. Bordering the Rio Puerco are part of its 1929 flood deposits, still partly barren of vegetation, and forming a large fanlike deposit which partially dams the Rio Grande. Levee breaks occurred in 1937 and 1941, in the background of this view, and there was considerable aggradation of the flood plain on both sides of the valley. The Rio Grande follows a straight, narrow, artificial channel for a short distance in the right side of the view.

FIGURE 2. LEVEE BREAK ON RIGHT BANK OF RIO GRANDE NEAR POLVADERA, DURING 1941 FLOOD

Part of river channel, with typical sand bars showing, in foreground. Several feet of sand was deposited in splaylike formations immediately beyond levee break, and lesser thicknesses of silt and clay farther away, near railway embankment which limited overflow in middle distance.

FIGURE 1. VIEW UP RIO PUERCO ARROYO, HERE ABOUT 40 FEET DEEP AND 400 FEET WIDE, SHOWING CHARACTERISTIC TRENCHING OF VALLEY ALLUVIUM
This is about 100 miles from the confluence with the Rio Grande. Cabezon Peak, a volcanic neck, is on the horizon.

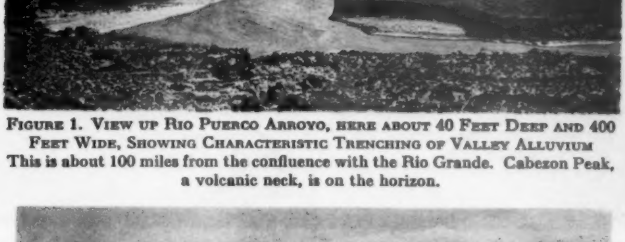

FIGURE 2. VIEW DOWN RIO PUERCO, FROM SAME POINT AS FIGURE 1
This shows the meandering habit especially well. The mouth of Arroyo Chico, a principal tributary from the Mt. Taylor region to the west, is in right distance.

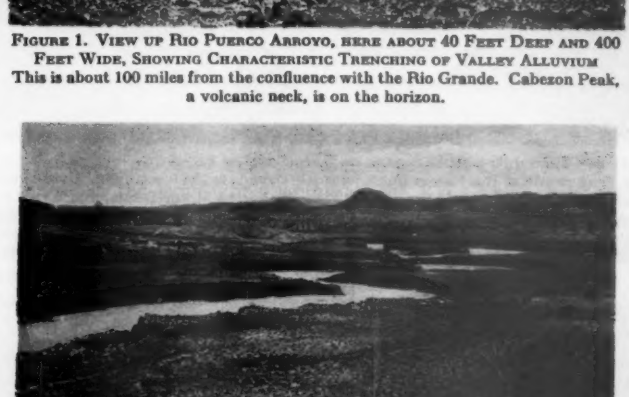

FIGURE 3. TYPICAL CAVING BANKS OF RIO PUERCO, COMPOSED OF ALLUVIAL SANDY CLAY (ADOBE), UNDERLAIN BY SAND
Intermediate banks formed on temporary deposits within main arroyo channel, on inside of migrating meander bends.

RIO PUERCO, LARGEST ARROYO TRIBUTARY OF THE MIDDLE RIO GRANDE

Rio Puerco to San Acacia, where there was comparatively rapid aggradation during the period 1927–1936, largely because of deposits from the Rio Puerco and Rio Salado floods of 1929. Since 1936 this reach has been degraded due to the dominance of channel scouring, as noted previously, but this is clearly a local condition.

In places the railway embankment has protected part of the flood plain from overflow, so that the difference in average ground elevation on either side may be a rough minimum measure of the amount of aggradation since railway construction in 1880. These differences amount to about 2 feet at Range 892, 1 foot at Range 969, and 2 or 3 feet at Range 977. However, there may have been some deposition back of the railway at the two latter places during the 1929 flood. At Range 977 the ground back of the railway was 1 or 2 feet higher in 1937 than a comparatively smooth surface shown at track line by the 1880 railway profile, and the aggradation on the riverward side thus may have been as much as 4 or 5 feet. In the vicinity of Range 969 it has been reported that there was 1 to 2 feet of deposition back of the railway during the 1929 flood (Poulson and Fitzpatrick, 1929), so that the aggradation on the riverward side there may have been 2 or 3 feet, instead of only 1 foot. On the other hand, there was no appreciable difference in ground elevation at Ranges 925.8, 929.9, and 982, although considerable parts of the flood plain lie behind the railway at these places. Irrigation-ditch banks or other local features may have prevented flood waters from reaching the riverward side of the railway at Ranges 925.8 and 929.9, but this does not appear probable at Range 982. Possibly deposition back of the railway, from local tributary sources, equaled aggradation on the riverward side at Range 982, or there may be some other reason why aggradation there was less apparent than seems to have been the general rule.

The evidence of appreciable floodway aggradation during the period 1936–1941 is one of the most significant facts brought out by the sedimentation studies. It is especially significant that this condition was shown even by comparative resurveys so soon after the major 1941 flood, and in large part by resurveys at times of comparatively high river stage. The number and distribution of the cross sections supporting this conclusion indicate that it represents the general tendency throughout practically the full length of the floodway. Thus it must be concluded that the present levee system cannot provide more than temporary flood protection, and that it affords no protection against continued aggradation and resultant rise in the ground-water levels and gradual reduction in the efficiency of the drainage ditches.

RATE OF RIVER AGGRADATION

The best available evidence of the rate of aggradation of the river, separate from the floodway, appears to be from comparisons with the water-surface elevations recorded on topographic maps made by the State Engineer's Office in 1917–1918 (Table 2). Studies of these maps proved that they were not sufficiently accurate in detail for reliable comparisons with the ground-surface profiles of 1936–1937, but the recorded water-surface elevations appeared more reliable. Comparisons of water-surface elevations are subject to many sources of possible error, but the results obtained from several trials of alternate methods of comparison, from studies of the range of magni-

tude involved in some of the variations incident to varying discharge stages, and consideration of river stages during the periods of the 1917–1918 mapping and the 1936–1937 surveys, led to the conclusion that the data might be used with some confidence. From these comparisons the average river aggradation from 1917–1918 to 1936–1937, weighted according to the distances between 38 points of comparison above Range 993.1, was 1.94 feet. The average period between measurements was 18.8 years, so that the average annual rate would be 0.10 foot per year, equivalent to 1 foot in 10 years. A similar weighted average for the river below Range 993.1 indicates an average annual rate of 0.21 foot per year, or about 1 foot in 5 years.

The most serious question concerning the accuracy of water-surface comparisons, as a measure of river aggradation, hinges on the relation of water surface to variations in discharge. On the Rio Grande, which scours and fills its bed on a considerable scale, the water surface may be either higher or lower after an increase in discharge, depending on local conditions as well as on the sequence of longer-period fluctuations in flow. Fortunately, however, both the 1917–1918 and 1936–1937 measurements were made at generally low stages, and following periods of more than a year without sustained high discharges such as would be expected to cause notable general scouring of the river bed. In 1941 flows up to 5000 second-feet generally did not cause much scouring, and at some places flows up to 10,000 second-feet scoured only relatively narrow channels within the wide river bed. The 1937 spring flood attained relatively high stage for a very brief period in the lower third of the valley, due to large local contributions, but it is doubtful whether this short period of high flow would do much scouring, and a few available measurements before and after the flood indicate no appreciable change.

The discharge at time of the 1936–1937 surveys is known from discharge records at stations above and below the various ranges. The approximate discharge can also be estimated, probably within a few hundred second-feet, from similar but less complete data for the periods, usually 10 to 20 days, during which water-surface measurements were made in each map-sheet area in 1917–1918. The discharges thus estimated, at 38 ranges used for comparison within the Conservancy District floodway, show averages of 960 second-feet in 1917–1918 and 880 second-feet in 1936–1937. The difference of 80 second-feet would ordinarily indicate a difference of less than a tenth of a foot in the water-surface elevation. At 12 ranges used for comparison below the floodway, the difference in the estimated average discharge likewise is less than 100 second-feet. Thus it appears that the water-surface measurements of 1917–1918 and 1936–1937 are closely comparable as averages, although comparisons for individual ranges or small groups might be subject to considerable error because of differences in discharge magnitudes.

Studies of the relations between average bed elevations, cross-sectional areas of water, water-surface elevations, and discharge volume were made from data obtained for the cross-section ranges during the surveys from 1936 to 1941. The relations between water surface and discharge were fairly consistent from 1936 through 1940, with the water-surface elevation generally increasing with discharge at rates of the order of a tenth of a foot for an increase of 250 second-feet. This relation varied approximately from a change of a tenth of a foot for 100 second-feet in the upper

reaches to about a tenth of a foot for 400 second-feet near the lower end of the valley. The relation between discharge and cross-sectional area of water was even more consistent. The ratio of variation between water elevation and discharge would also be expected to vary with the magnitude of discharge, but the data were not sufficiently complete to define this trend. Within the range of discharge differences involved in comparisons between the 1917–1918 and 1936–1937 data, corrections for differences in discharge did not alter the final averages by more than a tenth of a foot. A correction of this magnitude, subject to the unavoidably large errors in application, would not improve the data in terms of averages for the entire valley, for the present purpose. Therefore, the water-surface elevations have been compared directly, as listed in Table 2. The differences for individual ranges are not considered significant, except as they contribute to the averages for major sections of the valley.

The best evidence of the reliability of this method of comparison is afforded by the records of several series of ranges for which cross sections were surveyed in 1914, 1926, 1927, and 1936. One series consists of Ranges 903.4, 913.2, 918.3, and 925.8, located a little north of the middle of the Conservancy District floodway, and apparently well situated to represent average conditions. On these four ranges the average rate of river-bed aggradation for the period 1927–1936, as computed from cross-section surveys, is 0.07 foot per year; for the period 1918–1936, as computed from the water-surface elevations, it is 0.06 foot per year. The difference is obviously insignificant. Another group consists of Ranges 953, 956.3, 959.8, 963.5, 964.1, and 973.5, in the reach that appears to have been affected by abnormal aggradation due to sediment from the Rio Puerco and Rio Salado floods of 1929. Here the average rate computed from cross-section surveys is 0.48 foot per year during the period 1927–1936. The rate from 1918 to 1936, computed from water-surface elevations, is only 0.25 foot per year, but the aggregate change during this longer period was greater than that recorded for the shorter period. If the average rate from the cross-section surveys be accepted for the period 1927–1936, then the remaining part of the total aggradation for the period 1918–1936 indicates a rate of 0.04 foot per year for these ranges during the period 1918–1927. Such results appear to be consistent with the probable history of sedimentation.

In the lower section of the valley, below the Conservancy District levees, the average rate of river-bed aggradation on five ranges, first surveyed in 1926, was 0.32 foot per year for the period 1926–1936, as computed from cross sections. The average rate of aggradation on these same five ranges for the period 1918–1936, as computed from water-surface elevations, was 0.24 foot per year. Likewise, four ranges first surveyed in 1914 show an average rate of aggradation of 0.34 foot per year from 1914 to 1936 from cross-section records, and exactly the same rate per year for the period 1918–1936 from water-surface comparisons. These close agreements in the data from the two sources, and for different parts of the same period, are strong evidence of the essential reliability of the results from both methods.

The indicated rate of river aggradation within the floodway, about 1 foot in 10 years from 1917–1918 to 1936–1937, is also supported by even longer records from surveys beneath four railway bridges. These are Bridges 913-A near Isleta for which the records go back to 1897, 893-A near Belen and only a short distance downstream

TABLE 2.—*Comparison of Middle Rio Grande river surface elevations*

Range	Data from 1917–1918 maps		Data from 1936–1937 surveys		Apparent aggradation (feet)
	Approximate discharge (c.f.s.)	Water elevation (feet)	Approximate discharge (c.f.s.)	Water elevation (feet)	
860.4	1000	5225.9	1400	5227.2	1.3
864	600	5192.8	1450	5193.4	0.6
868	600	5162.2	950	5160.2	−2.0
878	550	5090.8	900	5093.5	2.7
883	600	5059.9	380	5062.0	2.1
884.8	1000	5049.4	1000	5050.3	0.9
887.5	1400	5036.6	1850	5037.9	1.3
892.9	1500	5005.9	550	5006.7	0.8
898	600	4976.6	1200	4978.3	1.7
903.4	600	4939.2	1800	4940.8	1.6
907.6	600	4919.9	1100	4920.2	0.3
913.2	600	4890.7	950	4892.0	1.3
918.3	1200	4865.5	1000	4866.8	1.3
922	1100	4846.2	900	4847.1	0.9
925.8	3000	4830.5	1300	4830.7	0.2
929.9	1800	4806.6	800	4811.1	4.5
934	2400	4791.6	1000	4793.2	1.6
937.5	1800	4776.7	800	4776.8	0.1
941	700	4760.0	450	4761.6	1.6
945	600	4742.5	400	4743.9	1.4
949	0	4725.0*	1270	4728.2	3.2*
950	0	4722.3*	580	4724.0	1.7*
951	0	4717.1*	650	4718.35	1.1*
952	0	4714.2*	730	4717.95	3.9*
953	0	4708.9*	1000	4715.3	6.9*
954	0	4704.6*	850	4711.4	9.5*
956.3	0	4694.9*	560	Not recorded	6.6*
959.8	400	4679.7	650	4686.4	6.7
963.5	500	4662.2	1220	4666.0	3.8
964	500	4659.9	1220	4664.1	4.2
964.1	500	4659.2	400	4662.0	2.8
969	1000	4634.4	1000	4637.3	2.9
973.5	1600	4610.2	1150	4611.1	0.9
977	1800	4592.4	400	4592.8	0.4
982	3000	4564.0	550	4566.4	2.4
985.9	3000	4546.3	350	4547.3	1.0
990	750	4527.9	750	4531.6	3.7
993.1	800	4515.9	10	4516.5	0.6
996.1	500	4500.2	5	4501.6	1.4
997(N)	500	4494.0	350	4497.3	3.3
998(L)	500	4488.5	300	4491.2	2.7
999(K)	500	4484.1	1000	4488.1	4.0
1000(J)	450	4480.1	300	4484.1	4.0
1001(I)	400	4475.1	600	4479.1	4.0
1002(H)	400	4471.0	100	4476.1	5.1
1003(G)	400	4467.7	100	4473.1	5.4
1004.6(E)	400	4462.1	400	4467.0	4.9
1005(D)	400	4460.1	200	4465.0	4.9
1005.7(C)	400	4456.8	100	4464.0	7.2
1006.4(B)	400	4453.7	650	4462.2	8.5

* River was dry at time of mapping in 1918; elevation given is for dry bed as shown by contours. Apparent aggradation determined by comparison with average bed elevation at time of 1936 surveys.

from Range 934 with a record beginning in 1904, 951-A across the Rio Puerco at the margin of the Rio Grande flood plain with a record beginning with 1904, and 961-A across the Rio Salado immediately above its confluence with the Rio Grande, for which the first detailed cross section dates from 1905. These records indicate aggradation varying from about 1 foot in 9 years to about 1 foot in 16 years for the longer periods. Individually these bridge cross-section comparisons would be of uncertain significance, but the general uniformity of results is significant. Comparisons with the less detailed 1880 construction profile appear to show lower rates prior to about 1905, but these comparisons are subject to even greater uncertainty.

The Rio Grande was shortened about 1½ or 2 miles by an artificial cut-off near San Acacia, to avoid bridging it in two places when the railway was built in 1880. This must have caused a local oversteepening of some 7 to 10 feet in the grade of the river. It is not surprising that this local steepening should since have been smoothed out, but this smoothing must have involved early upstream migration of a zone of incision initiated by the cut-off, including temporary degradation at the site of Range 963.5. This would normally be followed by aggradation, almost equal to the amount of degradation, as the river adjusted to a uniform grade. However, the records indicate aggradation has more than equalled the inferred temporary incision.

At the upper of the former river crossings the construction profile shows the 1880 river was about 700 feet wide, with an average bottom elevation of about 4661.5 feet. In 1928 the river-bed elevation was about 4662.9 at Range 963.5, which crosses the new channel only a few hundred feet away, and there were additional rises of about 1.5 feet by 1936, and another 1.4 feet by 1939. Data from a later survey at near-by Range 964.0 indicate that the filling from 1936 to 1939 probably was equalled or exceeded by scouring from 1939 to 1941. Thus the indicated rates of river-bed aggradation would be about 0.03 foot per year from 1880 to 1928, and 0.12 foot per year from 1928 to 1941. For the entire period 1880 to 1941, the average is 0.05 foot per year, equivalent to 1 foot in 20 years. If allowance be made for the degradation which probably occurred in the early part of the period of record, the actual rate of aggradation, subsequent to that temporary condition, may well have been similar to those rates computed for other parts of the river.

Thus, the average rate of aggradation indicated by the water-surface elevations, for the period 1918–1936, is consistent with the rates computed from cross-section surveys for shorter periods or for shorter parts of the river. This is not true for the period since 1936, however, because of the avulsions which have greatly altered the channel conditions and water-surface elevations south of the Conservancy District, and the scouring of part of the channel by the 1941 spring flood which lowered water-surface elevations much more than it lowered the average elevation of the entire normal or unvegetated channel. Comparison of the 1936–1937 water elevations with those of 1941 on the basis of approximate average depths and cross-sectional areas of water corresponding to the different discharge stages involved, produces results so erratic and so poorly correlated with the differences in average bed elevation recorded by cross-section surveys that they cannot be accepted as valid. The differences between width of water and width of unvegetated channel are commonly so great that there is no consistent relation between water-surface elevation and average river-bed

elevation, when large differences in discharge are involved, as is the case for the 1936-1937 and 1941 comparisons. Thus the water-surface elevations appear to be a reliable basis for measuring the rate of aggradation between periods of similar low discharge, but they are not reliable for comparison between times of very different discharge.

The general similarity in rates of aggradation as computed from cross-section surveys of the river and floodway for different periods and different parts of the valley, from water-surface elevations of 1917–1918 and 1936–1937, from the sections beneath railway bridges, and from ground-surface elevations on opposite sides of the railway embankment at several places where this has limited overflows since its construction justifies the conclusion that the various derived rates are essentially reliable and representative. There is no way of combining these data into a single figure for the average rate of aggradation, but together they suggest the rate of 1 foot of aggradation in 10 or 12 years is approximately correct for both river and floodway. This implies that the apparent lack of river aggradation within the floodway for the period 1936-1941 is abnormal, presumably because of the temporary effects of channel scouring by the 1941 spring flood, and that over a longer period the river and floodway berms may be expected to be aggraded at similar rates.

In the lower section of the valley, downstream from the Conservancy District floodway, the computed rate of river aggradation is about 1 foot in 5 years from 1917 to 1936, compared to 1 foot in a little over 2 years from 1936 to 1941 according to cross-section data. There is no reason to doubt that the rate will continue to be higher here than in the floodway, although the effects of avulsions and local channel scouring make it probable that the average will be below that indicated for the 1936-1941 period.

SOURCES OF SEDIMENT

General observations and qualitative data indicate that most of the Rio Grande sediment comes from channel or arroyo erosion in tributary valleys, but quantitative data on the relative contributions from different parts of the drainage area are meager.

Suspended-load sampling was carried on by the Soil Conservation Service from 1936 to 1941, at a number of sites on the Middle Rio Grande and principal tributaries, and has been continued at some of the sites since 1941 by the Corps of Engineers. In view of the physical difficulties in sampling under the conditions of highly erratic discharge and sediment concentration, sampling has generally been too infrequent to justify much confidence in computed amounts of sediment, such as those reported by Brown (1945, Table 1), but they suggest that the Rio Puerco (Pl. 4) contributes something like half the suspended load, with Galisteo Creek, Jemez Creek, and Rio Salado, the other principal tributaries, collectively contributing about as much as the Rio Grande from above Cochiti. The suspended-load records do not provide a reliable measure of the contributions from smaller tributaries but suggest that this is probably a minor factor. There is no doubt concerning the predominant importance of the Rio Puerco, but more adequate sampling would probably show the other main tributaries to be more important than is indicated by present records.

Minerals of the river-bed sands were studied in an effort to evaluate the sources of the coarser sediment not adequately represented by suspended-load sampling. The results (Rittenhouse, 1944) are not directly applicable to all the Middle Valley sediment, nor do they represent all sediment sources, but they can be applied to the total volume of 1936–1941 accumulation to obtain an estimate of the principal sand sources. This involves the assumption that sediment of all sizes was derived from the various sources in the same proportions as the sand, which is probably not greatly in error. If it be further assumed, without supporting evidence but apparently without seriously affecting the relative magnitudes of other values, that contributions from minor tributaries have been proportional to their drainage areas, one of the simplest methods of computation produces the following estimates of sand sources:

	Per cent
From Rio Grande above Cochiti	19
From Santa Fe Creek	1
From Galisteo Creek	3
From Jemez Creek	12
From Rio Puerco	35
From Rio Salado	13
From minor tributaries—assumed	17

Somewhat different figures can be derived by various other methods of application of the basic data, but apparently the relative magnitudes would not be altered significantly except perhaps for the upper Rio Grande which is most affected by the assumptions concerning minor tributaries. The mineralogical data are not directly applicable to the sediment carried into Elephant Butte Reservoir, but inclusion of the reservoir sediment in the totals would undoubtedly increase the importance of the Rio Salado and Rio Puerco relative to the upper tributaries. This would tend to bring the results into closer agreement with suspended-load data, in regard to the Rio Puerco. In general, therefore, the mineralogical studies indicate about the same relative importance for principal sand sources as the suspended-load data indicate for the finer sediment, and both types of data show that the sediment is derived chiefly from the lateral tributaries, rather than the main Rio Grande above Cochiti.

Similar, but even less complete, suspended-load and mineralogical data indicate that the greater part of the sediment originating above Cochiti is derived from the Rio Chama, which has in its drainage area a considerable proportion of arroyo-trenched tributary valleys.

CAUSES OF AGGRADATION

Excessive sediment output from channel or arroyo erosion in tributary valleys (Pl. 4) is believed to be the principal cause of the relatively high rate of aggradation in the Middle Rio Grande Valley, but the basic cause of the arroyo erosion is itself a matter of dispute, and several other influences may also be important.

In terms of geological structure, the Middle Rio Grande Valley is an area of depression, and in comparatively recent geological time it was the site of thick sediment accumulation—the Tertiary Santa Fe formation (Bryan, 1938). Subsequent to that

period of major aggradation there was a major period of stream degradation, trenching the Santa Fe formation to depths of some hundreds of feet and thus forming the present alluvial Middle Valley. Whether this period of general valley deepening continued until reversed by the recent arroyo trenching in tributaries is not certain. The unterraced flood plain, highest at the natural levees along the present channel, suggests a comparatively long period of aggradation, possibly due to geological influences antedating the present trenching of tributaries. Aggradation may, therefore, have been under way, but more slowly, for a period of centuries.

Climate also may have induced aggradation. The Middle Valley is an area of low precipitation, of the order of 10 inches per year according to present records. The effects of high evaporation, seepage into the pervious alluvium, and transpiration from vegetation along the river probably have long exceeded the effects of inflow from lateral tributaries, and thus depleted the flow of surface water entering the Middle Valley from higher areas of greater precipitation and runoff. Downstream diminution of flow thus has probably long been the rule and alone may have been sufficient to cause aggradation.

Irrigation has been practiced in the Middle Valley and certain tributaries since prehistoric time and has been greatly expanded in recent years. This increases the natural downstream depletion of river flow and also is directly responsible for aggrading some of the flood plain by deposition of sediment from irrigation water. Diversions for irrigation have been made on a large scale on headwaters of the Rio Grande in the San Luis Valley of Colorado, since about 1880, thus reducing the volume of comparatively clear mountain runoff water available for moving the sediment brought into the Middle Valley by the lateral tributaries.

Reagan (1924) ascribed the present arroyo erosion to a change in runoff regime resulting from widespread abandonment of former irrigation works in headwater valleys, but that theory has not been widely accepted.

There was a great expansion of cattle and sheep grazing throughout most of the Middle Rio Grande drainage area, as well as most of the Southwest, about 1870, and resulting depletion of natural vegetation and trampling of stock trails are commonly credited with starting the arroyo erosion, which became prevalent during the next 30 years. Tarr (1890) noted the influence of cattle trails in causing the lengthening of arroyos, and Dodge (1902) and Rich (1911) applied the overgrazing theory of arroyo erosion generally throughout the Southwest. More recently, Bryan (1925; 1927; 1928), Bailey (1935), Cooperrider and Hendricks (1937), Calkins (1941), and Thornthwaite, Sharpe, and Dosch (1942) have described much of the evidence linking the arroyo erosion to the influence of cattle and sheep, although Bryan does not consider this the primary cause.

Huntington (1914) specifically cited the arroyo erosion in the Southwest as evidence of climatic variation, considering it due to increased precipitation or increased storm intensities. Gregory (1917) ascribed the present "epicycle or erosion" to unusually heavy precipitation assisted by human agencies. Bryan (1928; 1940; 1941) elaborated the theory that recurrent periods of greater aridity have caused several periods of arroyo erosion in the Southwest, with grazing being only the "trigger-pull" which timed and set off the present erosional epicycle. This implies that the climatic

change to greater aridity occurred or at least began prior to accurate weather data, and hence is not a matter of direct record. This theory has considerable following, especially in connection with archeological studies. Unquestionably there were previous periods of arroyo cutting, possibly similar to the present, yet the existence of previous arroyos is not proof that the present ones are of similar origin.

The strongest argument against the theory of climatic cause appears to be the existence of essentially similar, but less publicized, channel erosion in minor valleys throughout much of the central and southern United States (Happ, Rittenhouse, and Dobson, 1940). There seems to be a gradation in arroyo-erosion conditions from the Southwest to the more humid regions where climatic variation surely has not been the principal cause of depletion of the natural vegetation. Clearly, widespread channel erosion in minor valleys of the central and southern States has been accelerated by human cultural influences including deforestation, cultivation, and grazing. These effects appear to be present continuously from the more humid to the more arid regions, with the arroyos more evident in the more arid regions only because there the individual valleys of intermittent or ephemeral runoff are longer and their arroyos larger. There is no apparent valid reason for believing that the similar effects have had different causes, in the more arid and more humid regions.

Whatever the primary cause of the present arroyo erosion, it is the principal source of Middle Rio Grande sediment and has been since late in the nineteenth century. Bryan (1927; 1928) has described considerable evidence supporting this interpretation in the case of the Rio Puerco and Rio Salado, principal tributaries of the Middle Rio Grande. It may also be noted that the A. T. & S. F. Railway crosses the Rio Puerco on a bridge about 300 feet long and 30 feet high, immediately above a concrete overfall structure 20 feet high, near where a bridge 100 feet long and 18 feet high was considered sufficient at the time of the first transcontinental railroad survey in 1853 (Whipple, 1856). Also, a segment of the pre-arroyo Rio Puerco channel, several miles long, has been preserved by some fortuitous channel avulsion subsequent to topographic mapping of the Albuquerque quadrangle in 1888 but prior to the channel enlargement in that vicinity. In the vicinity of Highway 66, west of Albuquerque, the present Rio Puerco channel is 300 to 600 feet wide and 30 to 40 feet deep, but the old channel was only about 100 feet wide and apparently little more than 10 feet deep, although wind-blown sand and rain wash have modified it somewhat and obscured its exact depth. In 1942 several dead cottonwood trees marked the bank of this old channel, a few hundred feet north of the highway and east of the present arroyo, and aerial photographs showed it plainly for a distance of several miles, following the alinement of the channel shown on the topographic map of 1888.

POSSIBLE REMEDIAL MEASURES

Several Federal agencies are engaged in extensive investigations directed toward preparation of plans for programs for improvement of grazing, irrigation, drainage, forest and soil conservation conditions, and flood protection in the Middle Rio Grande Valley and its tributary drainage basin. Such programs cannot be very effective in improving Middle Valley conditions over a long term unless the sediment problem

is solved. There is no certainty that the customary grazing controls or soil or forest conservation practices alone will check the arroyo growth, and flood-detention reservoirs or channel improvements on the main river will not solve the sediment problem. Some provision must be made to keep the sediment within the tributary valleys, either by large impounding structures or by development of measures for stabilizing the arroyo banks and inducing aggradation. The latter method would seem preferable, if technically feasible and if it could be made effective in time, because it might be less temporary and also have large secondary benefits in the improvement of grazing conditions and reduction of flood damage; but large sediment-impounding structures on main tributaries would be quicker and more certain. Choice between the two methods is a matter for engineering study, to determine costs of feasible plans, and for public debate as to the merits of the prospective benefits.

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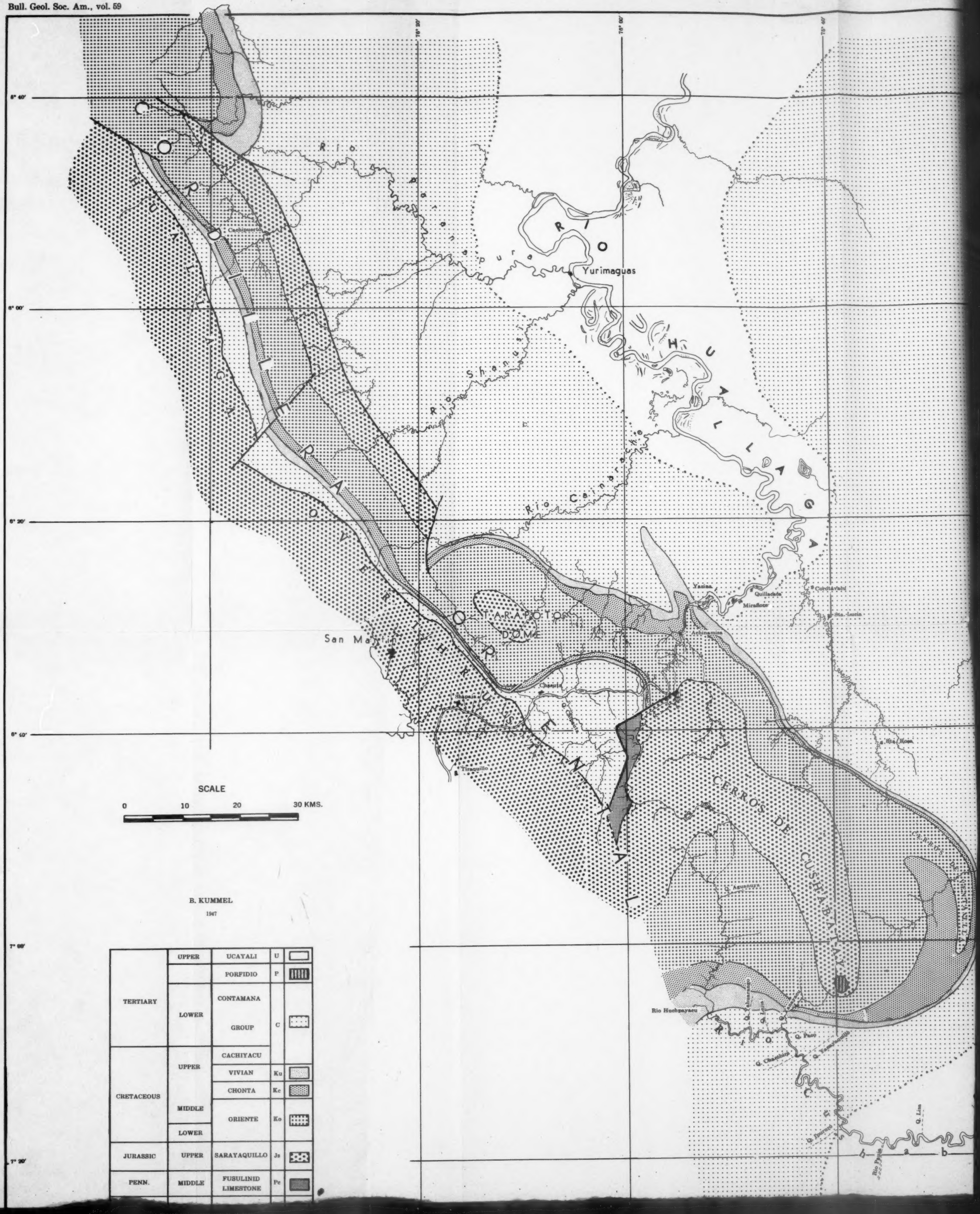
ROAD KILL



B. KUMMEL

1947

TERTIARY	UPPER	UCAYALI	U	
		PORFIDIO	P	
	LOWER	CONTAMANA GROUP	C	
CRETACEOUS	UPPER	CACHIYACU		
		VIVIAN	Ku	
		CHONTA	Kc	
	MIDDLE	ORIENTE	Ko	
	LOWER			
JURASSIC	UPPER	SARAYAQUILLO	Js	
PENN.	MIDDLE	FUSULINID LIMESTONE	Pe	

CORDILLERA HUALLAGA

CORDILLERA OVERTHRUST

Río Huallaga

Río Shanusi

Río Saposoa

Río Cachiyacu

Río Huallaga

Yurimaguas

Yaziaa

Quillachás

Miraflores

Cordillera

Sta. Lucia

Achinamisa

TARAPOTOS DOME

San Martín

Chasuta

Shapaja

Tarapoto

Sta. Rosa

Tirsquillo

CERROS DE CUSHIABATA

Aguanuya

CERROS DE CONTAMANA

Río Huchpayacu

Q. Pucú

Q. Chazuta

Q. Yamahuaquillo

Q. Iquarara

Q. Lima

Río Paranapura

SCALE

0 10 20 30 KMS.

B. KUMMEL

1947

TERTIARY	UPPER	UCAYALI	U	
		PORFIDIO	P	
	LOWER	CONTAMANA GROUP	C	
CRETACEOUS	UPPER	CACHIYACU		
		VIVIAN	Ku	
		CHONTA	Kc	
	MIDDLE	ORIENTE	Ko	
	LOWER			
JURASSIC	UPPER	SARAYAQUILLO	Js	
PENN.	MIDDLE	FUSULINID LIMESTONE	Pc	
ORDOVICIAN	MIDDLE	CONTAYA	Oe	

8° 40′ 8° 00′ 8° 20′ 8° 40′ 7° 00′ 7° 20′ 76° 40′ 76° 20′ 76° 00′ 75° 40′

GEOLOGIC MAP OF C

75° 20'
75° 00'
74° 40'
74° 20'
74° 00'
5° 00'
6° 00'
7° 00'
7° 20'

San Marcos
Río Pucuna
Río Tapiche
Río Yanacocha
Río Guarache
Río Ucayali
Río Pisqui
Río Sarayacu
Río Pachitea
Río Pisqui
Río Tapiche
Río Pachitea
Río Ucayali
Río Sarayacu

MAP OF CONTAMANA REGION, PERU

INDEX MAP

SOURCE OF INFORMATION

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GEOLOGICAL RECONNAISSANCE OF THE CONTAMANA REGION, PERU*

BY BERNHARD KUMMEL

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* The work for this report was done while the writer was in the employ of the Peruvian Government as geologist for the old Depatarmento de Petroleo del Cuerpo de Ingenieros de Minas, whose functions are now under a new organization called the Establecimientos Petroleros Fiscales.

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ABSTRACT

The Contamana region of eastern Peru includes part of the Cordillera Oriental of the Andes and the flat Amazon plain, cut by the Ucayali and Huallaga rivers. The area is of particular importance because it lies in the central regions of petroleum exploration programs. More than 6000 meters of Ordovician, Pennsylvanian, Jurassic (?), Cretaceous, and Tertiary rocks crops out. Most of this sequence is confined to the Cre.aceous and Tertiary. The Cretaceous rocks show transgressive

and regressive facies. The region was folded at the end of the Miocene and peneplaned by mid-Pliocene. There was subsequent epeirogenic movement of the whole region.

A stratigraphic nomenclature applicable to all of northeastern Peru is proposed, and the type sections are described.

INTRODUCTION

PREVIOUS WORK

Interest in the geology and petroleum prospects of the Oriente of Peru has been alternately active and passive for 25 years. Few authoritative publications exist. With the present renewed interest in petroleum in Peru it is hoped that more information will be published.

The first systematic and extensive geological exploration carried on in the area was by the Standard Oil Company of New Jersey under the supervision of H. R. Bassler. The work was started in 1922 and terminated in 1930; it was carried on in the regions of the Santiago, Marañon, Huallaga, Ucayali, and Pachitea rivers. The results were never published.

In 1924 and 1925 J. T. Singewald, Jr., made a general reconnaissance survey for the Gulf Oil Company from north of the Pongo de Manseriche to the Pichis and Pachitea rivers and across the Contamana Mountains to the Tapiche River; and a very general survey of the Huallaga River between Putante and Yurimaguas in 1924 (Singewald, personal communication). This resulted in two pioneer papers on the geology of eastern Peru (Singewald, 1927; 1928). The fossil faunas collected by Singewald have been studied by Pilsbry (1944) and by Knechtel and Richards (1947).

In 1931 Roberto L. Valverde, having spent some time with Bassler in eastern Peru, published a brief summary of the geology of the Huallaga country. A. Cabrera La Rosa published (1932) a geographic and geologic study of the valley of the Santiago River.

In 1929 Robert F. Moran discovered the Agua Caliente (or Ganzo Azul) dome during an airplane trip in the region of the Pachitea River. Moran and Fyfe explored the possibilities of this dome (1933).

Work in the Contamana region by the Departamento de Petróleo, Cuerpo de Ingenieros de Minas, was organized under the name of the Comisión Geológica de la Montaña with Fyfe as Chief. The first step in the exploration program was the making of an aerial mosaic of 1:30,000 scale of the Contamana region, covering an area of about 5000 sq. kms. At that time the Comisión consisted of Messrs. Fyfe, Richard Vosburgh, and Isaac Tafur. These men made a reconnaissance trip to Contaya late in 1942. N. D. Newell then joined the Comisión, and the group studied the aerial photographs stereoptically.

The Comisión made a reconnaissance trip to Agua Caliente Canyon in June 1943. Newell detailed the geology of Cachiyacu Creek later in the month, and in July the Comisión started detailed studies of the Santa Clara anticline. The author joined the Comisión at this time. In March 1944 the author was placed in charge of the geological exploration work, and surveys began in the Contamana Mountains and west of the Ucayali River to the Cordillera Oriental along the Sarayaquillo and

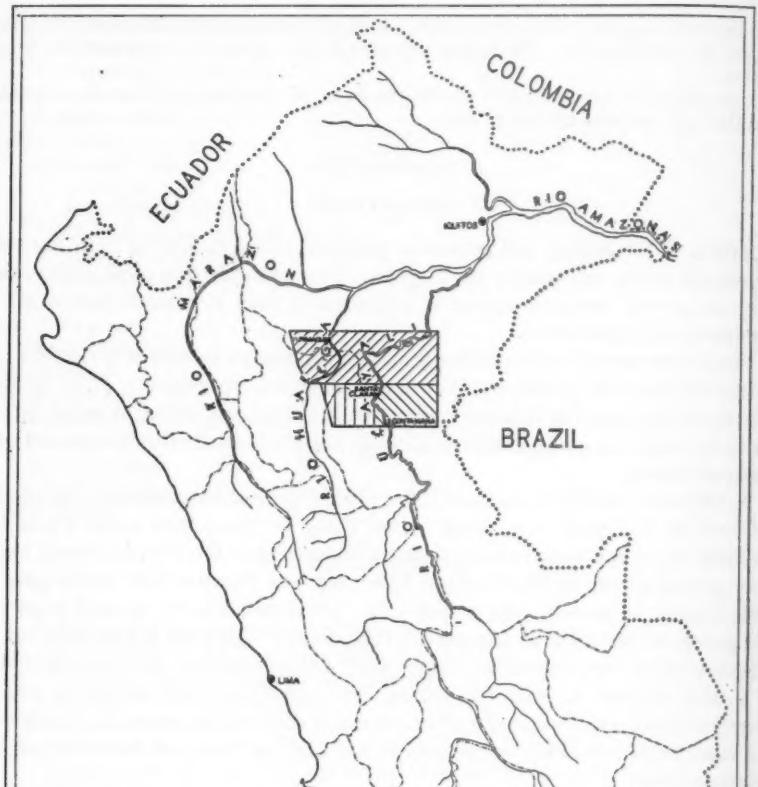


FIGURE 1.—*Index map of Contamana region*

Cushabatay rivers. Detailed studies in the Contamana Mountains were continued the following year.

LOCATION OF AREA

The Contamana region, in the Departamento de Loreto, Peru, includes part of the flat jungle terrain extending from the Cordillera Oriental eastward (Fig. 1). The

field work was confined to the drainage area of the Ucayali River between Contamana and Orellana. Much of the area east of the Contamana Mountains was studied only from aerial photographs. The whole northern half and the Huallaga area were studied from tri-metrogon aerial photographs. The area is quadrangular and crossed by the Huallaga and Ucayali rivers. It includes that part of eastern Peru between Lat. 5°30′ and 7°30′ S. and Long. 74°00′ and 77°00′ W., from the Tapiche River on the east to the Cordillera Oriental on the west. The more important towns are Contamana and Orellana on the Ucayali River and San Martin, Chasuta, and Yurimaguas in the Huallaga region. Access to the area is by the National Air Lines which runs a hydroplane service between Iquitos and Pucallpa; river launches also ply up and down the Ucayali between these two ports.

PURPOSE OF INVESTIGATION

The object of the work presented in this paper was to begin the geological studies of the area selected by the Departamento de Petróleo for petroleum exploration. The problem was approached first with emphasis on stratigraphy; later some specific work was done in the detailed mapping of prospective oil structures.

FIELD TECHNIQUE

The heavy vegetation in the jungles of eastern Peru conceals rock exposures; travel is possible only along trails; the best and only place to study the geology is along stream beds.

Factors of time, vegetation, and degree of accuracy were considered in choosing the way a particular field job was to be done. Detailed mapping of specific structures was by compass and pace traverses. The Sarayaquillo River was surveyed by compass, and the distances were approximated. Part of this river is included in the Contamana mosaic. The Cushabatay River was surveyed by transit.

The field studies of the areas within the Contamana mosaic were then added to the studies of the aerial photographs. These complementary tools produce the best results in heavily forested jungle regions. The stratigraphy was worked out in the field by the construction of profile sections.

Aside from the technical aspects of doing geological work in the jungle, problems of transportation, food, health, and general organization are of prime importance. No reliable source of food can be found in the jungle; thus it is imperative that all the supplies be carried. In the Contamana region there are no beasts of burden; lack of fodder and the density of vegetation make the use of mules, burrows, etc., impracticable. The medium of quick overland transportation is the *cargero* (native porter); the average peon can carry a cargo of about 40 kilos (88 pounds). The peon receives 1.28 kilos of food per day composed of fariña, rice, beans, dried fish, and coffee. The rations for the geologist consist of canned meats and vegetables, the amount being limited by factors of weight. The hunter occasionally can kill monkeys, peccaries, tapirs, and various types of fowl, which augment the food supply.

In the Contamana region there is essentially no malaria or yellow fever. During the day, especially along the rivers, small sand flies are disturbing; in the evening the mosquitoes are the major distraction. The days are very warm and humid, but the evenings are always cool, especially after midnight.

ACKNOWLEDGMENTS

The author wishes to express his sincere thanks to the Director of the Cuerpo de Ingenieros de Minas, Ing. F. Diaz, and chief of the Petroleum Department, Ing. A. Cabrera La Rosa, for their fine co-operation and for permission to publish this report. Sr. Armin Hoempler and Sr. Gustavo Iglesia ably assisted in the field. Dr. G. A. Cooper, assisted by Ralph Imlay, J. B. Reeside, Jr., and R. W. Brown, all of the U. S. National Museum, aided greatly in preliminary identifications of various fossils. Dr. Raymond Peck studied the fossil charophytes. Drs. H. D. Hedberg, R. E. King, Marshall Kay, and W. H. Bucher read the manuscript and offered many helpful suggestions. To these men I am very grateful. For the numerous hours spent with Dr. N. D. Newell discussing the geology of Peru and his great inspiration the author is indebted.

PHYSICAL CONDITIONS

TOPOGRAPHY

Topographically the Contamana region can be divided into the vast red-beds plane country and the hills and mountains. The division is usually very sharp and distinct. The plane is a peneplaned surface for which the name Ucayali peneplane is proposed. It lies 10–20 meters above the Ucayali and Huallaga rivers and is broadly undulating. The wide Ucayali and Huallaga flood plains are very striking geomorphic features on the Ucayali peneplane. Flood-plain deposits cover all rock outcrops adjacent to the main streams. These areas are usually flooded during the rainy seasons (Pl. 2).

East of the Ucayali River, between Contamana and Orellana, are the Contamana Mountains, trending northwest and rising some 2500 feet above the Ucayali peneplane. They are well dissected and contain several saddles. The western flank is outlined by hogbacks of Cretaceous sandstone. Throughout the Contamana region the high hills consist of sandstone, the lower areas of shale, and the flat planes of red beds. The topographic contrasts facilitate greatly the geological study of aerial photographs (Pl. 3). The Contaya Dome is low, oval, trends northwest, and is separated from the Contamana Mountains by a broad, low saddle, partly swampy. Northward from these two high areas and east of the Ucayali River, the terrain is low and swampy; most of it is covered by flood-plain deposits of the Ucayali River.

The Cordillera Oriental of the Andes bounds the western border of the region and forms the principal topographic high (Pl. 4). It reaches elevations of 5000 feet above the Ucayali peneplane in places and trends northwest. North of the Huallaga River the Cordillera is a narrow, deeply dissected mass which joins the Ucayali peneplane very abruptly. At the Huallaga River there is a long, narrow, northwestward-plunging nose. Southeastward from it, the Cushabatay Mountains form a broad spur of the Cordillera Oriental, which itself has a smaller spur, the Ventanilla Mountains, on the eastern side. The Cushabatay Mountains terminate southward in Cerro Paco, north of the Cushabatay River. The Cushabatay and Ventanilla spurs are enclosed by a continuous hogback of Upper Cretaceous sandstone. The central region of the Cushabatay Mountains has a peculiar type of topography,

FIGURE 1. UCAYALI RIVER, TOWN OF CONTAMANA, UCAYALI PENEPLANE, AND SOUTHERN HALF OF CONTAMANA MOUNTAINS
Photograph by the Servicio Aerofotográfico Nacional, Lima, Peru.

FIGURE 2. UCAYALI RIVER
Photograph by the Servicio Aerofotográfico Nacional, Lima, Peru.

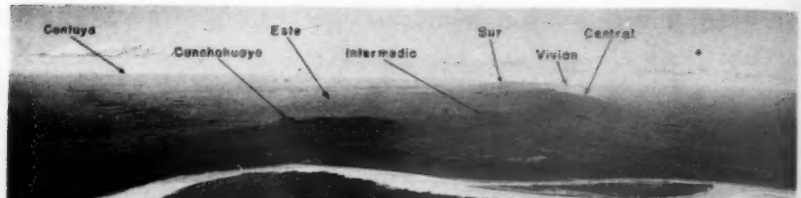


FIGURE 1. LOOKING SOUTHEAST WITH CONTAYA IN BACKGROUND
Names refer to closed structures within the Contamana Mountains. Photograph by the Servicio Aerofotográfico Nacional, Lima, Peru.

FIGURE 2. LOOKING ALMOST DUE SOUTH
Photograph by the Servicio Aerofotográfico Nacional, Lima, Peru.

CONTAMANA MOUNTAINS

named here "elephant butte", that is characterized by rounded, steep-sided, high, and isolated hills in a flat terrain.

DRAINAGE

The Ucayali and the Huallaga rivers control the drainage of the area. Between Pucallpa and the Amazon near Iquitos the Ucayali averages a kilometer (0.60 mile) in width. The Ucayali flood plain lies 145 meters above sea level at Santa Clara and approximately 120 meters at Iquitos and in places reaches a width of 40 kms. It is characterized by meander scars, oxbow lakes, swamps, natural levees, and cut-offs. The river follows a sluggish, broadly meandering course and abounds in islands, sand bars, and cut-offs typical of mature streams (Pl. 2).

The yearly fluctuation of the river level from wet to dry seasons averages around 8 meters. From May to November is generally dry; the rest of the year is characterized by heavy precipitation. From year to year, however, the beginning and ending of these seasons varies. Throughout the year the Ucayali is navigable by large river launches as far upstream as Pucallpa. The geomorphology of some of the rivers of eastern Peru, including the Ucayali and Huallaga, is well described by Cabrera (1943).

The tributaries of the Ucayali drain the eastern flanks of the Cushabatay Mountains and the western flanks of the Contamana Mountains. Almost all these tributaries are cutting their channels, and the red-bed plains are well drained, testifying to recent uplift of the region. Most of the smaller streams are consequents on the flanks of broad anticlinal hills. The Cushabatay River is a subsequent in its upper part where it occupies the southward-plunging syncline between the Cushabatay Mountains and the Cordillera Oriental. The Sarayaquillo River which flows eastward off the Cushabatay Mountains through sandstone canyons in the Ventanilla Mountains is a superimposed stream let down through Tertiary red beds. Likewise, *quebradas* (creeks) Huaya and Agua Caliente in the Contamana Mountains are superimposed streams; both occupy saddles in the Contamana Mountains.

The Contaya Dome has radial drainage. The western elements flow into the Ucayali just south of Contamana and north of Canchahuayo; the eastern elements empty into the Tapiche River, which joins the Ucayali at Requena.

The Huallaga River occupies deep canyons which trend diagonally across the Cordillera Oriental. After it leaves the Cordillera it flows in broad meanders parallel to the Cordillera. In this stretch the Cordillera Oriental is drained by three large tributaries of the Huallaga that occupy canyons in the mountain and broad meanders on the Ucayali peneplane.

ROCK EXPOSURE

Heavily forested regions such as the one under study contain few rock outcrops except along stream beds. The traverses upon which this report is based were made entirely along streams. The region has recently been uplifted, and even the lesser streams are cutting into their channels exposing rock outcrops. In general, shale outcrops are poor, while the sandstones form prominent scarps with continuous

exposures. Once beyond the Ucayali flood plain one can usually find satisfactory exposures.

The best exposures were along the Cushabatay River. In general, exposures are incomplete and discontinuous along the Sarayaquillo River. On the western flank of the Contamana Mountains the outcrops are excellent due to the steep dips of the formations.

SUMMARY OF STRATIGRAPHY AND NOMENCLATURE

Ordovician, Pennsylvanian, Upper Jurassic (?), Cretaceous, and Tertiary rocks crop out in the Contamana region. A porphyry intrusion in Cerro Paco is the only igneous rock exposed in the region. Most of the stratigraphic thickness is Cretaceous and Tertiary strata. As yet pre-Cretaceous rocks are only imperfectly known in the region east of the Cordillera Oriental. The oldest sedimentary formation is the Ordovician Contaya formation, exposed in Contaya. Pennsylvanian limestone is known only from river boulders seen along the upper Cushabatay River and from studies of the tri-metrogon aerial photographs. The Upper Jurassic (?) Sarayaquillo formation was studied in the field and in tri-metrogon aerial pictures; it is overlain with angular unconformity by the Cretaceous Oriente formation.

The Cretaceous sequence is over 2500 meters thick and is divisible into four formations: (1) The Oriente formation, Early and Medial Cretaceous in age, is 1700 meters thick in the Cushabatay region and only about 1000 meters thick in the Contamana Mountains, east of the Ucayali River. It is mostly coarse, massive, cross-bedded sandstone with interbedded shaly members. The distribution and relationships of the shales furnish the basis for its subdivisions. A marine tongue in the center of the Cushabatay section contains Aptian fossils. Another thinner marine tongue, about 200 meters below the top of the formation in the Contamana Mountains, contains Albian fossils. Aside from these two marine tongues the Oriente is thought to be essentially of continental origin. (2) The Chonta formation was deposited in a transgressive sea over the Oriente formation. The two formations are conformable throughout eastern Peru. They vary apparently in age from place to place, probably due to migration of the shore line during Medial Cretaceous time. The Oriente in the Cushabatay region is Neocomian to Turonian in age, and the Chonta, Turonian through Coniacian. East of the Ucayali the Oriente formation includes Neocomian and possibly some Turonian. The Chonta in this area apparently begins with the Coniacian. (3) The Chonta is overlain by the Vivian formation, a cross-bedded sandstone with interbedded black shales and laminated beds. The Vivian is identical lithologically to the more shaly facies of the Oriente formation. No unconformity could be clearly recognized between the Chonta and the Vivian. (4) Overlying the Vivian formation is a series of black, gray, and red shales and sandy shales, calcareous in part and containing a poorly preserved brackish-water fauna probably of Late Cretaceous age. This unit is approximately 150 meters thick and is termed the Cachiyacu formation. The Cachiyacu is the lowermost (Cretaceous) part of the enormous red-beds sequence which crops out extensively in eastern Peru.

The post-Cretaceous red beds that overlie the Cachiyacu formation are about

FIGURE 1. CORDILLERA ORIENTAL NORTH OF HUALLAGA RIVER
Js — Sarayaquillo formation, Ko — Oriente formation, Kc — Chonta formation, Kv — Vivian formation, C — Contamana group. Photograph by the Servicio Aerofotográfico Nacional, Lima, Peru.

FIGURE 2. HUALLAGA RIVER WHERE IT CROSSES CORDILLERA ORIENTAL
Pc — Pennsylvanian limestone; other symbols same as in Figure 1.

CORDILLERA ORIENTAL

3000 meters thick and have been named the Contamana group. This thick sedimentary sequence is divisible into five formations. No stratigraphic breaks are recognized within the Contamana group. Overlying the Contamana group with angular unconformity are flat-lying alluvial sand, clay, and boulder beds that are Late Tertiary in age, probably Pliocene.

The following descriptive section is for the Cushabatay region (Figs. 2, 3).

Geologic section exposed in the Cushabatay region

Ucayali formation (Pliocene)	
Clay, sand, and cobble beds, flat-lying, contains plant and wood fragments and small freshwater gastropods and pelecypods	30
—angular unconformity—	
Contamana group (Lower Tertiary)	
Ipururo formation	
Sandstone, gray-brown, concretionary, interbedded with red clay shale	1060
Chambira formation	
Shale, red, with small amounts of interbedded brown sandstone	680
Yahuarango formation	
Shale, red, purple, green, black, with interbedded siltstone beds, fossiliferous	925
Casa Blanca formation	
Sandstone, white, fine-grained	60
Huchpayacu formation	
Shale, red, clay	240
Cachiyacu formation (Post-Chonta Cretaceous)	
Shale, gray and black, silty in parts, contains marine and brackish water fossils	100
Vivian formation (Post-Chonta Cretaceous)	
Sandstone, white, yellow-brown, cross-bedded, with black shale and laminated units, contains mica flakes and plant fragments	220
Chonta formation (Turonian-Coniacian)	
Shale, black and gray, siltstone, calcareous, and some marl beds, very fossiliferous	400
Oriente formation (Lower and Middle Cretaceous)	
Huaya member (Albian-Cenomanian)	
Sandstone, white, yellow-brown, cross-bedded, with black shale and laminated beds, contains plant fragments and mica flakes	120
Agua Caliente member (Aptian-Albian)	
Sandstone, white, yellow-brown, cross-bedded, massive, with iron concretions	520
Paco member (Aptian)	
Sandstone, white, yellow-brown, cross-bedded with black shale and laminated beds, contains fragments and mica flakes	75
Esperanza member (Aptian)	
Shale, black, sandstone and limestone, with marine fossils	150
Aguanuya member (Aptian)	
Sandstone, white and yellow-brown, cross-bedded, with black shale and laminated, contains plant fragments and mica flakes	155
Cushabatay member (Neocomian)	
Sandstone, white, yellow-brown, reddish, massive, cross-bedded, contains fossil wood	750
—angular unconformity—	
Sarayaquillo formation (Upper Jurassic?)	
Sandstone, red, fine-grained, cross-bedded	?
— unconformity —	
Pennsylvanian limestone	
Limestone, gray, siliceous, cherty, fossiliferous	?

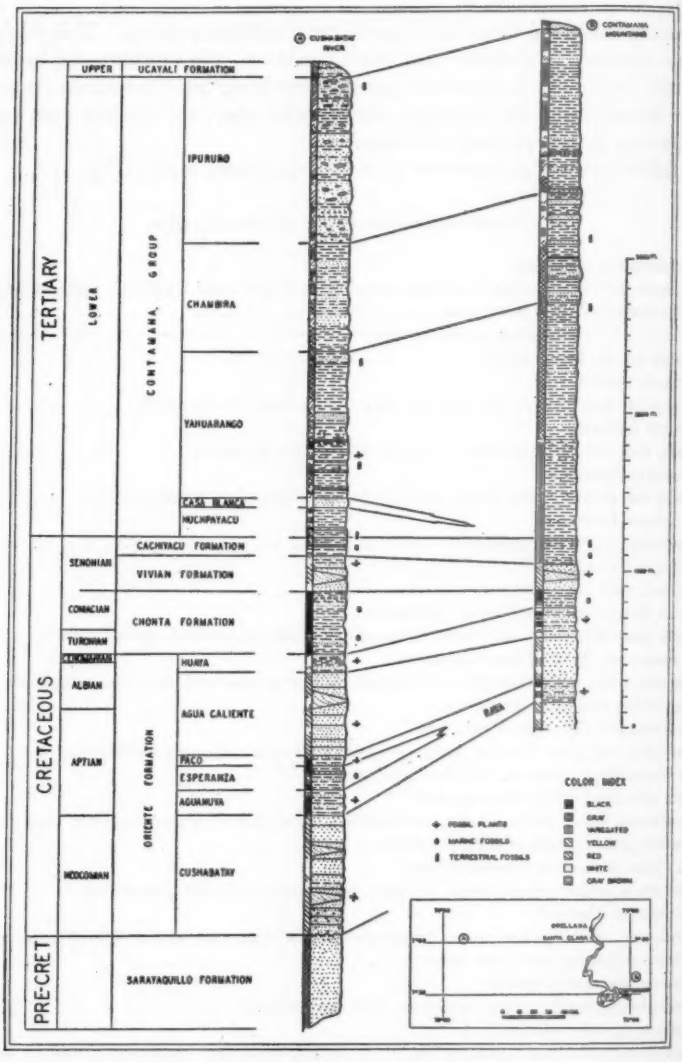


FIGURE 2.—*Stratigraphic sections of Contamana region*

East of the Ucayali River the section varies somewhat from the Cushabatay section. The Casa Blanca sandstone of the Contamana group is not present. The Chonta formation is confined to the Coniacian and averages 150 to 200 meters in thickness. The marine Esperanza member is not present in the Oriente formation. As a result the Paco and Aguanuya facies constitute one lithologic unit which is here named the

Raya member. Moreover, the Oriente is only about 1000 meters thick. The Sarayaquillo formation and the Pennsylvanian limestone have as yet not been recognized east of the Ucayali River. In Contaya, the Contaya formation (Ordovician) underlies the Oriente formation.

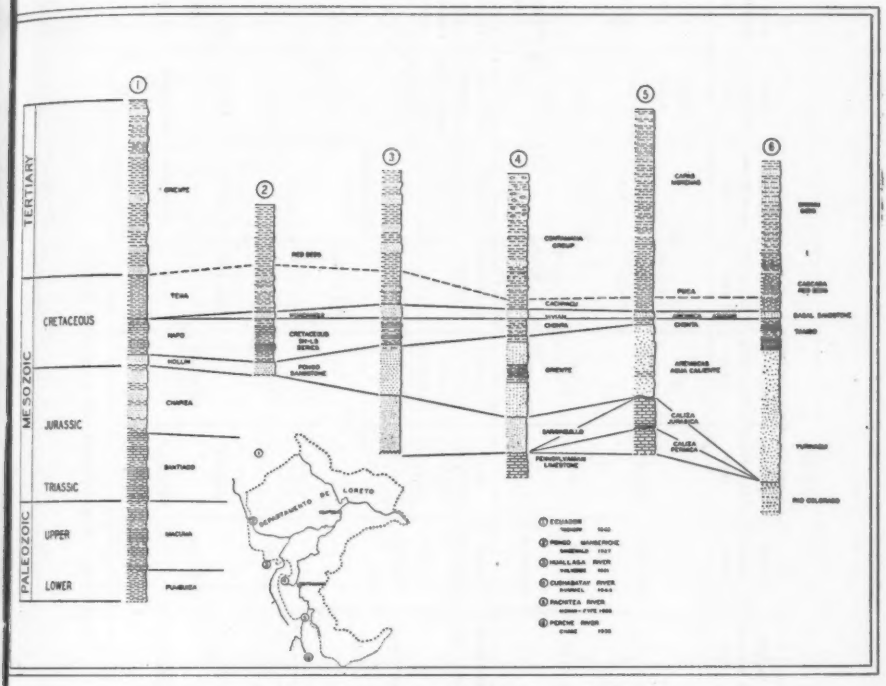


FIGURE 3.—*Stratigraphic sections of eastern Peru and Ecuador*

ORDOVICIAN ROCKS

CONTAYA FORMATION

Ordovician rocks were first seen in the Contaya Dome by the Comisión Geológica de la Montaña in 1942. Newell and Tafur (1943; 1944) first recognized the Ordovician age of these rocks (Fig. 5a). The Contaya formation consists of 150 meters of medium-gray, well-laminated argillaceous shales, underlain by massive quartzite of unknown thickness and age. The formation is overlain with slight discordance by Cretaceous sandstone.

The fossils of the Contaya formation belong to the graptolite facies so characteristic of the Middle Ordovician rocks of the Andes of Peru and Bolivia (Newell and Tafur, 1944). The fauna belongs to the zone of *Didymograptus murchisoni* which is older than the zone of *Nemagraptus gracilis*, the lower Normanskill of North America, and younger than the zone of *Didymograptus bifidus* approximately equivalent to

		Tschopp Ecuador 1945	Oppenheim Serra de Cuiuc 1943	Singewald Pto. Manseriche 1927	Kummel Rio Cushabatay 1944	Fyfe Newell Cº de Contamana 1943	Kummel Cº de Contamana 1945	Olivera - Leonardos Territorio do Acre 1943	Oppenheim Serra do Moa 1937	Singewald Rio Pachitea 1928	Moran Fyfe Rio Pachitea 1933	Chase Rio Perene 1933
TERTIARY		CURARAY USHPA CHAMBIRA ARAJUNO PASTAZA	RED BEDS	RED BEDS	CONTAMANA GROUP CACHIVACU	CONTAMANA GROUP CONTAMANA FORMATION	CONTAMANA GROUP CACHIVACU	FORMACAO PUCA	CRUZEIRO RED BEDS	BROWN BEDS RED BEDS	CAPAS MORENAS FORMACION PUCA	CASCADA RED BEDS
CRETACEOUS	UPPER Senonian	FORMACION TENA	ARENISCAS BLANCAS	? HUACANQUI SANDSTONE	? VIVIAN FORMATION CHONTA FORMATION	? VIVIAN FORMATION CHONTA FORMATION	? VIVIAN FORMATION CHONTA FORMATION	? FORMACAO DIVISOR	? SUNGURU SANDSTONE	? HUACANQUI SANDSTONE	ARENISCAS AZUCAR FORMACION CHONTA	BASAL SANDSTONE TAMBO LIMESTONE
	MIDDLE Turonian Cenomanian Albian Aptian	FORMACION NAPO	FORMACION CUTUCU	CRETACEOUS SH.-LS. SERIES	ORIENTE FORMATION		ORIENTE FORMATION	FORMACAO RIO AZUL	CRETACEOUS SH.-LS.	CRETACEOUS SH.-LS.		
	LOWER Neocomian	FORMACION HOLLIN	ARENISCAS INFERIORES	PONGO SANDSTONE		ARENISCA FORMATION NEOCOMICA		FORMACAO MOA	MOA SANDSTONE	PONGO SANDSTONE	FORMACION AGUA CALIENTE	YURIMAQUI SANDSTONE

FIGURE 4.—*Nomenclature and correlation chart*

Deepkill shale; thus the fauna is lower Middle Ordovician. The graptolite facies of the Middle Ordovician is extensively developed in Peru and Bolivia, and the Contaya exposure is the northernmost occurrence there.

Tschopp (1945) records two areas of early Paleozoic rocks in eastern Ecuador

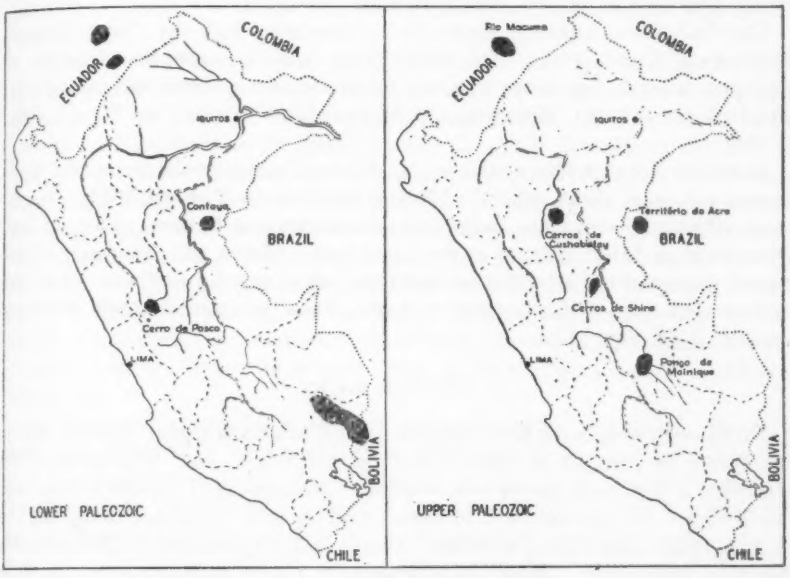


FIGURE 5.—*Paleozoic outcrop maps*

which have as yet yielded no diagnostic fossils. In the southern part of the Cutucú Mountains black and gray-black argillaceous shales (Pumbuiza formation) have yielded only questionable lingulas. The formation is overlain by Carboniferous limestone with angular discordance. A unit similar to the Pumbuiza—the Margajitas formation—outcrops west of Topo in the Pastaza valley. It is composed of semimetamorphic argillaceous shales and sandstones containing poorly preserved fossils.

PENNSYLVANIAN ROCKS

Upper Paleozoic rocks crop out in several places in the Oriente[1] of Peru (Fig. 5b). In the Contamana region along the upper reaches of the Cushabatay River, 250 kms. above the mouth, boulders and cobbles of hard, gray, siliceous limestone containing productids and fusulinids were found on the rocky bars. The actual outcrop area was never reached, but the area was studied on tri-metrogon aerial photographs, which show that the limestones are brought to the surface along a northeast-south-

[1] Oriente and Montana are two terms often used for the eastern lowlands.

west fault. They apparently underlie the Sarayaquillo formation unconformably. The outcrop area of these limestones is relatively small. Fusulinids from some of the cobbles were sent to C. O. Dunbar who reports that they are a new species closely similar to *Fusulina peruana* Meyer (*see* Dunbar and Newell, 1946) and of Des Moines age. He also noted the presence of the Bryozoa *Prismapora* which in North America is common in the Des Moines.

The Cushabatay exposures appear to be correlative with the Tarma group of Dunbar and Newell (1946). The Tarma group consists of more than 1000 feet of dark-gray to black, limy shales with interbedded fossiliferous limestones containing a Middle Pennsylvanian (Moscovian-Des Moines) fauna (Dunbar and Newell, 1946, p. 385).

In eastern Ecuador 1400 meters of blue siliceous limestones alternates with argillaceous and sandy shales called the Macuma formation by Tschopp (1945). It contains a Pennsylvanian fauna in the lower 500 meters and Tschopp points out that Permian is probably included in the upper part. Moura and Wanderley (1938) record fine-grained Carboniferous quartzite and quartzitic sandstone from the northwestern part of the Territory of Acre. These sandstones contain *Productus cora* (R. E. Oliveira, 1936).

PERMIAN ROCKS

No Permian rocks have been recorded in the Contamana region; however, recent discoveries of Permian in eastern Peru warrant mentioning. Thompson (1943) described a Wolfcamp species now referred to *Schwagerina* (?) *patens* Dunbar and Newell from the discovery well in Ganzo Azul oil field. The core containing the fusulinid came from 1458 to 1464 feet. Ganzo Azul is approximately 150 kilometers south of Contamana. Heim (1947) assigned a Lower Permian age to the thick limestone sequence exposed along the Pongo de Mainique in the Urubamba River.

JURASSIC ROCKS (?)

SARAYAQUILLO FORMATON

In the upper Cushabatay region and at Cerro Paco the Oriente formation is underlain, apparently with angularity, by a red, fine-grained, cross-bedded sandstone named the Sarayaquillo formation. The formation is soft and incompetent in comparison with the Oriente formation. As it is clayey and massive, dips are very difficult to obtain. At Cerro Paco the Sarayaquillo formation is faulted against the Oriente formation in three places; both formations are duplicated several times in small faults along Quebrada Porfido. Just beyond one of the faults an excellent outcrop shows the Sarayaquillo formation in angular unconformity with the lower Oriente formation. The Oriente is strongly cross-bedded and dips 20° S. 10° E., and the Sarayaquillo dips 6° N. 75° E. This is the only contact seen. Outcrops are poor, and few reliable dips were obtained. In the Yanayacu section the uppermost part of the Sarayaquillo formation is white to gray; this grades very uniformly downward into a deep red in a vertical thickness of less than 100 meters. Several

units of the Sarayaquillo formation have 10-cm. cream-colored beds of sandstone spaced about a meter apart. In many places the Sarayaquillo formation contains small pebble like concretions of sandstone. The Sarayaquillo outcrop along Quebrada Porfido is warped and faulted throughout. It is intruded by a basic porphyry toward the center of the mountain. The Sarayaquillo has been altered in places to quartzite. There are numerous xenoliths of the Sarayaquillo sandstone in the porphyry.

Studies of tri-metrogon aerial photographs show that the Sarayaquillo has a rather extensive outcrop area in the Cushabatay Mountains. The formation is characterized by striking "elephant butte" topography. It is underlain to the west by the Pennsylvanian limestone formation, probably unconformably.

A partial section of the Sarayaquillo formation was examined west of the Huallaga River along the upper reaches of the Paranapura River. Here the formation is a fine- to medium-grained red sandstone, very massive, and hard. It differs from the red sandstone of the Cushabatay region in its greater resistance and coarser texture. However, only the upper part of the formation was studied in the Cushabatay region and only the lowest part in the Paranapura region where it forms high massive scarps. On the map the two outcrop areas have been shown by a similar pattern. Possibly, however, these two outcrop areas of red sandstone belong to different formations.

The Sarayaquillo formation is post-Pennsylvanian and pre-Neocomian. Since it is associated closely with the Pennsylvanian limestones in the Cushabatay region it may be correlative with the Yauli formation of the Tarma region (Permian or Pennsylvanian). In eastern Ecuador the Cretaceous Hollin sandstone is underlain by the Chapiza formation which is also a red sandstone containing much volcanic material. The Sarayaquillo may be correlative with the Chapiza, which Tschopp (1945) considers Upper Jurassic.

PRE-CRETACEOUS OROGENY (NEVADIAN?)

The angularity between the Sarayaquillo formation and the Oriente formation indicates orogeny. In the Contamana region the lower Cushabatay member of the Oriente formation contains limestone cobbles lithologically similar to the Pennsylvanian limestone of the Cushabatay Mountains. The Oriente rests on rocks of varying age. In the Pachitea region it lies on Jurassic (?) and Permian limestones (Moran and Fyfe, 1933). In Contaya, the Oriente rests on the Ordovician Contaya formation, and farther east in the Serra do Môa it lies on Carboniferous rocks. In the upper Cushabatay region it rests on the Jurassic (?) Sarayaquillo formation and in eastern Ecuador on the Jurassic Chapiza formation.

Lack of faunal data makes specific dating of this orogeny impossible in the Contamana region. However, it seems to be the same as a Jurassic folding which affected much of the Andean region (Hedberg, 1942). In the Chicama Valley of northern Peru Stappenbeck (1924) described a succession of shales and marls with siliceous limestone concretions with a Portlandian fauna. These grade up into a series of sandstones, shales, and coal beds of terrestrial origin yielding Neocomian

plants. A somewhat similar relationship was found in the Arequipa region by W. F. Jenks (Newell, personal communication). It thus seems highly probable that the orogeny took place during the Oxfordian and/or Kimmeridgian. Weeks (1947, p. 1212–1213) places the late Jurassic orogeny in the Kimmeridgian.

CRETACEOUS ROCKS

ORIENTE FORMATION

Definition.—The Oriente formation is a massive, coarse- to fine-grained, white to yellow-brown sandstone with some interbedded shale beds. It underlies the Chonta formation conformably. The basal contact at the few places where it is visible is clearly an unconformity. The Oriente forms a massive core in nearly all prominent structures in the Contamana region. Topographically, it makes prominent ridges cut here and there by steep-walled canyons. The name, Oriente formation, has been chosen because of the economic importance of this rock unit in the Peruvian Oriente, and the Cushabatay River is selected as the type locality.

Distribution and thickness.—The Oriente formation is well exposed throughout the Contamana region; it is the central unit of the Contaya Dome, the Contamana Mountains, the Ventanilla Mountains, and the Cushabatay Mountains. Only the upper part is exposed in the Contamana and Ventanilla mountains. In the Canchahuayo anticline an incomplete section of 500 meters of the Oriente formation is exposed. Ruegg (1947, p. 82) reports that the well Raya No. 1 of the Cia. Peruana de Petroleo "El Oriente" in the Canchahuayo anticline was stopped at 2600 feet in a synodiorite. Along Quebrada Huaya, 526 meters of the Oriente formation crops out; southward in the Central Anticline along Quebrada Raya 900 meters of the Oriente is visible. Along a tributary from Sur Anticline that joins Quebrada Agua Caliente just below the Vivian sandstone scarp, 700 meters of the Oriente formation was measured. In the Santa Clara anticline only about 50 meters of the Oriente formation is exposed in the center of the structure.

Along the Sarayaquillo River in the Ventanilla Mountains the Oriente formation is badly broken by several tear faults. However, farther west where the Sarayaquillo River flows out of the Cushabatay Mountains, 755 meters of the Oriente formation was measured. Along the upper Cushabatay River is a section of 1770 meters of the Oriente formation underlain unconformably by the Sarayaquillo formation.

South of the Contamana region along the Pachitea River, Moran and Fyfe (1933) found that the Oriente ranges from 1300 to 1600 meters and is underlain along the Yamiria River by pre-Cretaceous limestone. In the Agua Caliente well No. 1, at Ganzo Azul, Permian limestone directly underlies the Oriente.

Moura and Wanderley (1938) record 400 meters of the Oriente formation in the Serra do Môa, Territory of Acre, Brazil. Oppenheim (1937) has also described the Oriente from this region but gave no estimate of its thickness

North of the Contamana region in the Pongo de Manseriche, Singewald (1927) found only 300 meters of the Oriente exposed, which he referred to as the Pongo sandstone. In eastern Ecuador the Hollin sandstone, the Oriente equivalent, ranges

from 100 to 250 meters in thickness. The Hollin sandstone rests unconformably on the Jurassic Chapiza formation.

Stratigraphic and lithologic features.—The Oriente formation is a pure quartz sandstone which in places contains abundant quartz pebbles 2 to 4 mm. in diameter, in thin lenses on bedding planes and cross laminations. Conglomerate beds are present almost throughout the section. The Oriente is characterized by abundant iron concretions in the form of sheets on bedding planes or in rounded irregular masses throughout the formation, most abundant in the upper part. The sandstone is strongly cross-bedded, and torrential cross-bedding and cut-and-fill structures are common. Hot springs emitting warm sulfurous waters flow from the upper part throughout the outcrop area.

There are abundant beds of black and gray shales concentrated mostly in the upper and middle parts of the formation, and associated in many horizons are laminated beds of white and gray siltstone. The shales and siltstone usually contain abundant mica (muscovite) flakes and plant fragments.

Early workers paid little attention to the details of lithology and stratigraphy. Regional field studies in the Contamana region revealed several distinct facies recognizable from one region to another. The outcrops along the Cushabatay River are the most complete in the region and have been selected as the type section. They are of great interest because a marine member is found in the middle. Six members within the Oriente formation are recognized, which represent three distinct facies. The members from top to bottom are

(6) Huaya member—sandstone and shale containing plant fragments and mica flakes; named after Quebrada Huaya in the Contamana Mountains.

(5) Agua Caliente member—massive, cross-bedded sandstone; named after Quebrada Agua Caliente in the Contamana Mountains.

(4) Paco member—sandstone and shale containing plant fragments and mica flakes; named after Quebrada Paco a tributary of the Cushabatay River.

(3) Esperanza member—marine facies of black shale with some interbedded limestone and fine-grained sandstone; named after Puerto Esperanza along the upper Cushabatay River.

(2) Aguanuya member—sandstone and shale with plant remains and mica flakes; named after Quebrada Aguanuya a tributary of the Cushabatay River.

(1) Cushabatay member—massive, cross-bedded sandstone; named after the Cushabatay River.

The Huaya, Paco, and Aguanuya members are very similar in stratigraphic sequence and lithologies, as are the contrasting Agua Caliente and Cushabatay members. Eastward the Esperanza member disappears, and the central shale zone is occupied by a member similar to the Paco, Huaya, and Aguanuya. This middle shale zone in the Contamana Mountains is called the Raya member. The general characteristics of the other members are constant. The lithologic chaarcteristics of the members of the Oriente formation are given in detail in the stratigraphic sections. (*See also* Figures 2, 10, 11.)

The Oriente formation in the Pachitea region has been described by Singewald

(1928) and Moran and Fyfe (1933). It is 1300 to 1600 meters of cross-bedded sandstone with some interbedded shale. Approximately 600 meters from the top of the formation is a 150–200 meter bed of shale. No fossils were found in this zone (Fyfe, personal communication), but it is equivalent to the middle shale members of the Cushabatay region or the Contamana Mountain region. The lower part of the Oriente in the Pachitea region contains thin beds of a limestone conglomerate.

The Yurinaqui sandstone (Chase, 1933), exposed along the Perené River, seems to be at least partly equivalent to the Oriente formation. The Yurinaqui for the most part is coarse-grained sandstone, strongly cross-bedded, and contains pebble layers; the upper part is of light-colored sandstone with interbedded limestone. Chase mentions that detailed studies would enable subdivision of the Yurinaqui. Hot springs and tar seeps occur at various places in the Yurinaqui sandstone.

In the Pongo de Manseriche the Pongo sandstone, as described by Singewald, is lithologically similar to the Oriente of the Contamana region. As only 300 meters of the sandstone is exposed in the Pongo de Manseriche information on the lower part of the section is lacking. The Hollin sandstone of eastern Ecuador is very similar lithologically to the Oriente. The Hollin is only 100 to 250 meters thick and in certain zones is saturated with a petroleum asphalt. Where the bottom contact is observable, it overlies the Jurassic Chapiza formation with angular discordance (Tschopp, 1945).

In the Territory of Acre, Brazil, the Oriente is represented by the formação Moa (A. I. Oliveira and Leonardos, 1943). Oliveira and Leonardos recognized two members within the formação Moa—the lower "Camadas Capanaua" member of 100 meters of pink and yellow sandstone with frequent shale zones, and a 3 meter conglomerate bed at the base. The Capanaua unconformably overlies Carboniferous (?) quartzites. The upper member, the "Camadas Moa", consists of 300 meters of fine-grained, cross-bedded sandstone, with quartz pebbles.

Stratigraphic sections.—The following sections have been carefully selected to illustrate the lithologic features of the Oriente formation.

Quebrada Raya, Central anticline, Contamana Mountains

	Thickness of bed in meters	Top of bed to base of Oriente
Huaya member, covered	200	905.5
Agua Caliente member		
17. Sandstone, white to yellow brown, massive, contains iron concretions, quartz pebbles, with interbedded units of fine-grained sandstone, forms first scarp in Agua Caliente member. The hot springs in this region issue from the top of this member	50	705.5
16. Sandstone, white, laminated with black shale, contains plant fragments and mica flakes	12	655.5
15. Sandstone, white and yellow brown, massive, conglomeratic, cross-bedded, forms canyons	68	643.5
14. Sandstone, white, fine-grained, massive, cross-bedded, lower part coarse-grained	50	575.5
13. Sandstone, white, thin-bedded, 1- to 2-inch black shale breaks, interbedded with laminated white sandstone	25	525.5

	Thickness of bed in meters	Top of bed to base of Oriente
12. Sandstone, white to yellow brown, coarse, conglomeratic, massive, strongly cross-bedded, has some interbedded units of white, fine-grained sandstone in upper part	65	500.5
Raya member		
11. Shale, red and purple, argillaceous, silty, mottled gray in places	6	435.5
10. Siltstone, black, argillaceous, carbonaceous, contains plant fragments and quartz pebbles	4	429.5
9. Sandstone, white, thin-bedded, laminated with layers of black clay shale	15	425.5
8. Lignite bed, sheets of carbonaceous matter containing pieces of wood replaced by pyrite	0.5	410.5
7. Sandstone, massive to thin-bedded, laminated with black, clay shale, also shale beds up to 1 meter thick, some gray-brown mottled siltstone; whole unit contains abundant carbonaceous material in form of wood and plants, and mica flakes	140	410
Cushabatay member (incomplete)		
6. Sandstone, white to yellow brown, coarse, cross-bedded, contains abundant iron concretions, with occasional quartz pebbles up to 10 cm. in diameter, interbedded with numerous thin laminated beds of fine-grained, clayey, white sandstone; in lower part are some beds of red and gray sandstone	150	270
5. Sandstone, white, fine-grained, massive, cross-bedded, with abundant laminae and scattered zones of a dark mineral; lower part contains some medium-grained sandstone in massive lenticular units	60	120
4. Sandstone, white, coarse, conglomeratic, massive, cross-bedded, contains laminae of a dark mineral	45	60
3. Sandstone, purple, medium-grained, with quartz pebbles	2	15
2. Siltstone, gray, clayey, mottled purple	2	13
1. Sandstone, white, with laminae of a dark mineral, interbedded with red and gray clayey siltstone	11	11
Total	905.5	

Quebrada Huaya, Contamana Mountains

	Thickness of bed	Top of bed to base of exposed section
Huaya member		
28. Siltstone, gray brown, massive, iron-stained, contains plant remains	6	540
27. Shale, blue gray, clayey, well bedded	6	534
26. Siltstone, gray blue, massive, relatively soft	6	528
25. Shale, blue gray	2	522
24. Shale, blue gray, silty in parts, contains iron concretions and stains	6	520
23. Covered, probably gray-brown siltstone	16	514
22. Siltstone, gray, clayey, massive, iron-stained on surface	2	498
21. Shale, gray blue, well bedded	8	496
20. Siltstone, gray brown, both massive and shaly	10	488
19. Covered	6	478
18. Siltstone, gray, thinly laminated	24	472
17. Sandstone, white, massive, cross-bedded, weathers greenish	2	448
16. Siltstone, gray brown, thinly laminated	2	446
15. Sandstone, gray and brown, massive	2	444

	Thickness of bed	Top of bed to base of exposed section
14. Siltstone, gray brown, thinly laminated; contains some interbedded gray blue shale beds with fossil plants	2	442
13. Sandstone, yellow brown, massive, contains concretions	5	440
12. Sandstone, white, massive	2	435
11. Siltstone, gray brown and blue gray, massive, soft, iron-stained	3	433
10. Covered	12	430
9. Sandstone, gray white, massive, cross-bedded, with a 1-meter bed of soft blue-gray siltstone which is iron-stained on the surface	5	418
8. Shale, blue gray, silty, contains laminae of white siltstone	2	413
7. Shale, blue gray, clay shale	2	411
6. Siltstone, gray brown, iron-stained	10	409
5. Shale, blue gray, well bedded	2	399
4. Siltstone, blue gray, shaly	14	397
3. Siltstone, chocolate brown, massive	13	383
Agua Caliente member (incomplete)		
2. Sandstone, yellow brown with white and gray horizons; massive, cross-bedded, coarse, contains rounded quartz pebbles averaging 2–3 mm. in diameter; contains springs emiting hot sulfurous water. Sandstone around hot springs contains much pyrite	350	370
1. Sandstone, gray, thin-bedded, with interbedded units of blue-black clay shale containing fossil plants	20	20
Total	540	

Quebrada Pumayacu, Canchahuayo anticline, Contamana Mountains

	Thickness of bed	Top of bed to base of exposed section
Huaya member		
4. Sandstone, yellow brown, massive, cross-bedded, with interbedded beds of gray-brown siltstone and black shale, contains numerous plant remains in places	200	465
3. Shale, black, with interbedded units of gray-brown, fine-grained sandstone, contains pelecypods, cephalopods (*Lyelliceras* aff. *L. pseudolyelli*), *Lingula*	30	265
2. Sandstone, yellow brown, with interbedded units of laminated white siltstone and black shale, contains plant fragments	45	235
Agua Caliente member (incomplete)		
1. Sandstone, white and yellow brown, massive, cross-bedded, contains quartz pebbles	190	190
Total	465	

Quebrada Agua Dulce, Canchahuayo anticline, Contamana Mountains

	Thickness of bed	Top of bed to base of exposed section
Huaya member		
9. Siltstone, gray brown, clayey, shaly, and massive, interbedded with black shale and fine-grained sandstone; in places the black shale contains liminae of white siltstone	70	465

	Thickness of bed	Top of bed to base of exposed section
8. Siltstone, blue black, and black shales with thin interbedded units of white sandstone	5	395
7. Sandstone, white, thin-bedded to massive, cross-bedded, with interbedded black shale and laminated gray siltstone, contains plant fragments	40	390
6. Sandstone, brown, with interbedded clayey white, massive siltstone and gray-black shales which contain laminae of reddish-brown siltstone	20	350
5. Sandstone, gray white, fine-grained, with interbedded units of hard, coarse, yellow-brown sandstone	10	330
4. Sandstone, white, with iron concretions, interbedded with gray-white siltstone and laminated gray-black shales, contains mica flakes and fossil plant fragments	45	320
Agua Caliente member (incomplete)		
3. Sandstone, yellow brown, cross-bedded, massive, contains quartz pebbles	180	275
2. Sandstone, gray white, fine-grained, laminated gray brown, contains fossil plants	5	95
1. Sandstone, yellow brown, cross-bedded, massive, contains quartz pebbles	90	90
Total	465	

Sarayaquillo River

	Thickness of bed	Top of bed to base of exposed section
Huaya member		
7. Sandstone, white, gray, and yellow brown, fine- to coarse-grained, massive and thin-bedded, contains iron concretions, some interbedded black shale beds present	65	755
6. Siltstone, gray brown, massive, soft, contains iron concretions and interbedded units of black shale; detrital bone fragments, fossil teeth and plants present	45	690
5. Siltstone, gray brown, calcareous, surface covered with iron concretions, contains small detrital bones and fossil teeth	1	645
4. Siltstone, gray brown, massive, soft, with interbedded black shale units	35	644
3. Siltstone, gray brown, calcareous, iron encrusted on surface	1	609
2. Siltstone, gray brown, shaly, with interbedded plant-bearing black shale beds	33	608
Agua Caliente member		
1. Sandstone, yellow brown to white, massive, strongly cross-bedded, contains numerous iron concretions usually in form of sheets on bedding planes and cross-bedded plane; contains quartz pebbles up to 3–4 mm. in diameter; some thin interbedded units of black shale and gray-brown siltstone	575	575
Total	755	

Quebrada Yanayacu, Cerro Paco, Cushabatay Mountains

	Thickness of bed
Huaya member	
4. Sandstone, yellow brown and gray, fine-grained, with interbedded black black shale beds and partings	120
Agua Caliente member	

	Thickness of bed	Top of bed to base of exposed section
3. Sandstone, yellow brown to white, coarse, cross-bedded, massive, forms prominent canyon	480	
Paco member		
2. Sandstone, gray and yellow brown, thin-bedded, laminated with black shale, interbedded with black shale and gray siltstone beds; contains plant fragments and mica flakes	160	
Esperanza member (incomplete)		
1. Shale, black, interbedded with gray siltstone, contains limestone concretions, fossiliferous, with pelecypods, cephalopods, gastropods, teeth, and bones	60	
Total	820	

Cushabatay River, Cushabatay Mountains

	Thickness of bed	Top of bed to base of exposed section
Huaya member		
22. Sandstone, yellow brown and white, cross-bedded, with iron concretions, with interbedded black shales and shaly sandstone beds containing plant fragments and mica flakes	120	1770
Agua Caliente member		
21. Sandstone, yellow brown, coarse, massive, strongly cross-bedded, contains iron concretions, quartz pebbles and occasional thin shale or siltstone bed with plant fragments and mica flakes	520	1650
Paco member		
20. Sandstone, gray brown, fine-grained, laminated, contains iron concretions in form of sheets on bedding plane; interbedded with black shales, gray shales, and gray siltstone beds; mica flakes and plant fragments present	55	1130
19. Shale, black, silty, with occasional laminae of white siltstone; interbedded with fine-grained, laminated, gray-brown sandstone; mica flakes and plant fragments present	20	1075
Esperanza member		
18. Shale, black, contains fossil teeth, bones, pelecypods	30	1055
17. Limestone, gray, sandy, very hard, compact, fossiliferous	2	1025
16. Shale, black, fossiliferous	20	1023
15. Limestone, gray, sandy, fossiliferous	1	1003
14. Shale, black	20	1002
13. Limestone, gray, hard, sandy	1	982
12. Sandstone, mottled brick red and maroon in irregular patches, massive	5	981
11. Shale, black, silty	3	976
10. Sandstone, red, massive	5	973
9. Shale, black	4	968
8. Siltstone, gray brown	1	964
7. Shale, black	1	963
6. Siltstone, with numerous iron concretions	1	962
5. Siltstone, gray brown, shaly	2	961
4. Shale, black, with limestone concretions in lower part	40	959
3. Shale, black, with interbedded beds of dark, reddish-brown sandstone, shaly	14	919

	Thickness of bed	Top of bed to base of exposed section
Aguanuya member		
2. Sandstone, white and yellow brown, thin-bedded, laminated with black shale in places; interbedded with black shales and gray siltstone beds; tains mica flakes and plant fragments	155	905
Cushabatay member		
1. Sandstone, yellow brown and white, massive, with some thin-bedded units, strongly cross-bedded, contains quartz pebbles; toward bottom of member are some black and purple shale and siltstone beds with plant remains; also cobbles of limestone and scoria present in scattered conglomerate beds; sandstone contains current ripple marks	750	750
Total	1770	

Correlation.—Marine fossils are rare in the Oriente formation. However, small but diagnostic faunas were found in the Esperanza and Huaya members. R. W. Imlay of the United States National Museum recognized *Psilomya lissoni* Sommereier in the Esperanza and mentions that it is a common form in the upper Aptian of South America. From the Huaya fauna, Imlay recognized *Lyelliceras* aff. *L. pseudolyelli* (Parona and Bonarelli) and comments that *Lyelliceras* is known only from the upper lower Albian and the lower middle Albian. "*Lyelliceras* (studied by Maxwell Knechtel) is abundant in the basal part of the shale and limestone overlying the Pongo sandstone" (Imlay, personal communication). Specimens of fossil wood from the lower Cushabatay member were also sent to the United States National Museum, and R. W. Brown reports that they cannot be identified. The Cushabatay member is considered Neocomian on a stratigraphic basis. It underlies marine Aptian conformably and is similar in lithology and stratigraphic position to well-dated Neocomian units in the Central Andes.

In eastern Ecuador the Hollin sandstone, Cushabatay equivalent, underlies the Napo formation conformably (Tschopp, 1945). The lower Napo is Aptian.

No unconformity has been recognized between the Chonta and Oriente formations; the relations of the two are believed to be of replacement overlap of the Chonta over the Oriente toward the east with occasional regressions. The age of the top of the Oriente formation varies from place to place, depending on the age of the base of the overlying Chonta facies. In the Cushabatay region the Oriente extends through the Cenomanian; and the lower Chonta is Turonian. In the Contamana Mountains the upper Oriente includes the Turonian, and the Chonta is confined, apparently, to the Coniacian. The problem of dating the upper Oriente is not quite so difficult as with the lower Oriente Cushabatay member. More fossiliferous horizons should be discovered in the Huaya member when further work is done, but the Cushabatay member has so far proved to be barren except for unidentifiable plants and wood fragments. The lower Oriente formation may be Aptian, but the author doubts it.

Origin.—Most of the Oriente formation represents fluvial deposition. The massive cross-bedded sandstones were laid down on a peneplaned surface of folded Ordovician, Pennsylvanian, Permian, and Jurassic rocks. The common occurrence

of torrential cross-bedding, the coarseness of the sand, degree of rounding, interbedded micaceous silty shales with plant detritus, occasional plant and lignite layers, and current ripple marks testify to fluvial deposition. The source of the sediments was apparently the Brazilian shield to the east (Fig. 10). The Cushabatay member is believed to be entirely fluvial laid down by active and loaded streams during Neocomian time. The Aguanuya member, of shales and sandstone, upon which was deposited the marine beds of the Aptian Esperanza member, represents the shore facies of a transgressive sea. The extent of the marine transgression to the east is not known. The marine tongue is not present in the Contamana Mountains east of the Ucayali River; thus it reached some point west of the Ucayali in this region. This transgressive phase probably coincides with an erosional reduction in elevation of the distributive province and a marked decrease in the competence of streams.

The Paco member is interpreted as a regressive shore facies of the Esperanza sea. This regression of the geosynclinal sea to the west culminated in the deposition of the fluviatile Agua Caliente member. The extent of the regression is not known. The time was late Aptian or early Albian. Later in the Albian the sea again advanced eastward, and the Huaya member represents the shore facies of this transgression. During the Albian the sea advanced as far as the Contamana Mountains and then retreated. Upon the Huaya facies this transgressive sea deposited the Chonta formation. This second transgressive phase extended from the Albian through at least part of Coniacian time.

CHONTA FORMATION

Definition.—The Chonta formation in the Contamana region is composed of dark-gray shale with interbedded units of siltstone, calcareous siltstone, and some limestone. To the south, along the Pachitea River, and to the north in the Pongo de Manseriche, the Chonta includes massive limestones. The Chonta conformably overlies the Oriente formation and underlies the Vivian formation with apparent conformity. It is a relatively nonresistant unit, hence exposures are usually poor and incomplete. The formation was named (Moran and Fyfe, 1933) after Isla Chonta in the Pachitea River, where fine exposures have yielded abundant fossils.

Distribution and thickness.—In the Canchahuayo anticline the Chonta formation is 150 meters thick. Excellent exposures are seen along Quebrada Agua Dulce. The same thickness for the Chonta was found in the Central anticline. Between the Canchahuayo and Central anticlines along Quebrada Huaya is a very good exposure of almost the entire formation. Exposures on the east side of the Contamana Mountains are very few because the surface is low and swampy and alluvial deposits cover most of the area. On the west side of the Contamana Mountains the exposures are generally good because of the higher gradient of streams and the narrower belts of outcrop due to steep dips.

Along the Sarayaquillo River on the east flank of the Ventanilla Mountains the Chonta formation is 300 meters thick. This section is only partially exposed. The Chonta is continuously exposed between the Ventanilla and Cushabatay mountains. In this outcrop area, however, the formation is badly faulted, and measurements are not possible.

On the southeast flank of the Cushabatay Mountains at the foot of Cerro Paco along the Yanayacu River, the Chonta is 220 meters thick. Farther west along the Cushabatay River it is 400 meters thick. In the Contamana region the Chonta formation converges eastward. Between the Contamana Mountains and the Cushabatay Mountains (100 kilometers), the Chonta increases 275 meters.

In the Territory of Acre, Brazil, in the Serra do Môa region, the Chonta, called the formação Rio Azul by A. I. Oliveira and Leonardos (1943), consists of 800 meters of dark-blue and gray clay shale, calcareous sandstone, and thin limestone. Along the Pachitea River the Chonta has been studied by Singewald (1928), Moran and Fyfe (1933), and Heim (1947). Singewald called the Chonta the Cretaceous shale and limestone series and found it to be about 150 meters. Moran and Fyfe reported about the same thickness, and Heim measured only 50–70 meters. Farther south along the Perené River, Chase (1933) reports 2000 feet (650 meters) of Chonta equivalents which he called the Tambo limestone. In the Pongo de Manseriche, Marañon River, Singewald (1927) found the Chonta to be about 910 meters. Wasson and Sinclair (1927) and Tschopp (1945) report on Chonta equivalent, called the Napo formation, in eastern Ecuador. Wasson and Sinclair estimated the Napo to be 1500 feet (500 meters). Tschopp found the Napo to range from 350 to 800 meters.

Stratigraphic and lithologic features.—The Chonta formation in the Contamana region is a shale sequence with interbedded calceroeus siltstone and marly beds. On the east side of the Ucayali River in the Contamana Mountains, the Chonta is entirely gray shale and calcareous siltstone. The shale is blue gray, black, and gray brown. The colors in places are in thin alternating laminae or beds. Some of the shale beds are silty and in places contain laminae of siltstone. At infrequent intervals thin units of calcareous siltstone and limestone concretions are present. The siltstone beds are gray brown, yellow brown, and blue gray. The siltstones are massive to shaly. Iron concretions are present in places, and thin beds of sandstone. West of the Ucayali River, the formation is more calcareous.

The Sarayaquillo section is mostly covered, but the middle part of the section is well exposed and consists of an alternating sequence of gray to black shales and gray, gray-brown, and gray-black siltstones with several interbedded calcareous beds. In general, the Chonta is lighter-colored than on the east side of the Ucayali River.

The best-exposed section of the Chonta formation studied in the Contamana region is along the Cushabatay River. The Cushabatay section differs markedly from the more eastern outcrops in containing thick, light-gray, calcareous and argillaceous siltstones. The whole section is an alternating series of black shale and gray calcareous siltstone beds. The siltstones are hard, fracture conchoidally, and are massive. They form a prominent series of ridges all along the outcrop area. Limestone concretions in regular zones are present at short intervals.

In the Contamana region the Chonta conformably overlies the Oriente formation. This same relationship exists throughout eastern Peru, eastern Ecuador, and western Brazil where the Chonta has been studied and reported on. Areas of the Chonta formation north and west of the Contamana region are characterized by a great increase in limestone.

Along the Pachitea River the Chonta consists of gray, nodular-fracturing shale and calcareous shale that weathers gray to grayish white and grades into thin beds of darker gray to blue-gray fissile shale. Interbedded with the shale are many beds of limestone ranging from 1 to 2 meters. The limestone is smooth-textured, gray, massive or divided by bedding planes at intervals of 2 to 15 cm. The Chonta in the Pachitea region is very fossiliferous.

Along the Perené River the Chonta equivalent, called the Tambo limestone by Chase (1933), is shaly limestone or a very calcareous shale carrying abundant dark, cherty nodules. The shale layers are abundant and somewhat darker than the limestones. Here also the formation is very fossiliferous.

Along the Abujao River, east of the Ucayali River, the Chonta formation consists of blue, gray, and red clay shales and limestone (Oppenheim, 1937).

In extreme eastern Peru and the Territory of Acre, Brazil, the formation is dark-blue and gray clay shales, very calcareous sandstone, and thin limestone intercalations. Some of the shales are brick red and contain calcareous concretions, (Oppenheim, 1937; Moura and Wanderley, 1938).

In the Pongo de Manseriche it is gray shale with interbedded limestones. The shales are light gray to almost black and in places are highly calcareous, grading into argillaceous, nodular limestone. The limestone units range up to 100 meters and vary from light-gray pure limestone to dark-gray, slaty limestone. Sandstones of appreciable thickness are also included in the series, the most prominent being near the top and the bottom of the section. The prominent top sandstone member that Singewald called the Huacanqui sandstone probably is the Vivian sandstone of this report.

The Napo formation in eastern Ecuador consists of gray and black limestone with calcareous sandstone and blue and black clay shale. The limestone contains siliceous concretions. The Napo is bituminous and is considered by Tschopp to be a possible source rock of petroleum.

Stratigraphic sections.—The following sections have been carefully selected to illustrate the lithologic features of the Chonta formation.

Cushabatay River, Cushabatay Mountains

	Thickness of bed in meters	Top of bed to base of formation
7. Shale, black, mostly covered, lower part with two or three 1-meter beds of gray siltstone and some limestone concretions, contains *Ostrea*, echinoids, bones, *Lingula*, pelecypods	65	401
6. Shale, black, mostly covered	90	336
5. Shale, black, with soft, silty, gray-black beds, fossiliferous, contains limestone and pyrite concretions	20	246
4. Siltstone, gray to gray brown, calcareous in places, with interbedded black shales and a few 1-foot limestone beds, also limestone concretions at intervals, fossiliferous	85	226
3. Shale, black, with interbedded gray and gray-brown siltstone beds, calcareous in places, also limestone concretions, fossiliferous	65	141

	Thickness of bed in meters	Top of bed to base of formation
2. Sandstone, white, fine-grained, weathers gray	1	76
1. Siltstone, gray and gray brown, calcareous in places, with interbedded black shale units, fossiliferous	75	75
Total	401	

Sarayaquillo River, Ventanilla Mountains

22. Covered	102	330
21. Siltstone, gray, hard, forms small scarps	2	228
20. Shale, light gray, iron-stained	4	226
19. Shale, light gray, clay shale, iron-stained, with a 1-meter interbedded gray-brown siltstone bed, contains small turritellids	10	222
18. Siltstone, gray, calcareous, both massive and irregularly bedded, contains ammonoids, gastropods, and pelecypods	2	212
17. Shale, gray, clay, well bedded	4	210
16. Siltstone, gray, calcareous, contains thin beds of limestone, has cephalopods, pelecypods, and gastropods	4	206
15. Shale, gray black, clay, well bedded	6	202
14. Shale, gray, calcareous, fossiliferous	2	196
13. Shale, gray black, clay shale, well-bedded, silty in part, contains some fossils	8	194
12. Siltstone, gray brown, irregularly bedded	2	186
11. Shale, gray black, well bedded, has small concretions of iron, some fossils present	12	184
10. Shale, gray black, interbedded with gray shaly siltstone, contains abundant bones, round iron concretions	8	172
9. Siltstone, gray brown, irregularly bedded, shaly in part, fossiliferous, *Ostrea*	10	164
8. Siltstone, gray brown, calcareous, irregularly bedded	2	154
7. Siltstone, gray, irregularly bedded, forms small scarps	6	152
6. Shale, gray black, well bedded, poorly exposed	10	146
5. Siltstone, dark gray, irregularly bedded	4	136
4. Siltstone, light gray, calcareous, hard, fossiliferous	2	132
3. Siltstone, gray black, irregularly bedded	1	130
2. Shale, gray black, well bedded, iron-stained	4	128
1. Covered	124	124
Total	330	

Quebrada Agua Dulce, Canchahuayo anticline, Contamana Mountains

7. Shale, blue gray, with interbedded units of gray-brown siltstone, also contains a 1-meter bed of light-gray calcareous siltstone	20	160
6. Shale, gray brown, silty, with interbedded units of blue-gray shale	20	140
5. Shale, blue gray, fossiliferous with bones and pelecypods, contains several very thin calcareous siltstone beds and limestone concretionary beds	45	120
4. Siltstone, yellow brown, clayey, fossiliferous with pelecypods, teeth, and bones	2	75
3. Shale, blue gray, silty in parts	12	73
2. Siltstone, gray brown	1	61
1. Shale, blue gray, interbedded with gray-brown siltstone beds	60	60
Total	160	

Quebrada Huaya, Canchahuayo anticline, Contamana Mountains

	Thickness of bed in meters	Top of bed to base of formation
19. Covered	13	165
18. Siltstone, gray, clayey, massive	2	152
17. Shale, gray black, contains laminae of white siltstone	3	150
16. Sandstone, gray, iron-stained	1	147
15. Sandstone, whitish gray, shaly, soft	2	146
14. Covered	4	144
13. Siltstone, gray brown, mottled yellow brown, contains iron concretions, massive	20	140
12. Shale, gray black, clayey, iron-stained, well bedded; contains fossil teeth, bones, and pelecypods	15	120
11. Shale, blue gray, iron-stained, interbedded with shaly gray-brown siltstone beds	17	105
10. Siltstone, gray brown and light gray, stained yellow brown, both shaly and massive	15	88
9. Sandstone, gray brown, contains interbedded clay-shale beds with laminae of white siltstone	12	73
8. Shale, blue gray, clayey, well bedded	5	61
7. Sandstone, steel gray, calcareous, hard, massive, contains *Ostrea*, *Pecten*, and turritellids	2	56
6. Siltstone, blue gray, clayey, massive, mottled, yellow brown	3	54
5. Shale, blue gray, clayey	10	51
4. Siltstone, gray brown, light gray in parts, clayey, shaly, has interbedded clay shale beds	25	41
3. Shale, gray blue, with laminae of white siltstone, upper part grades into gray-brown clayey siltstone	5	16
2. Sandstone, gray, hard, compact, contains teeth and bones; outcrop forms small rapids in river	1	11
1. Covered	10	10
Total	165	

Correlation.—The Chonta formation in the Contamana region is fossiliferous. The sections studied east of the Ucayali River in the Contamana Mountains are generally poor in fossils, but *Ostrea*, *Pecten*, *Turritella*, fish teeth, and bone fragments have been encountered. Several unidentified species of pelecypods are also present. Singewald (Knechtel, Richards, and Rathbun, 1947) found *Tissotia reesideana* Knechtel, *T. obesa* Knechtel and *T. steinmanni* Lisson at Petronilla, on the west flank of the Canchahuayo anticline. Throughout the Chonta in this area, reworked bone fragments, subangular to rounded, are present. Associated with the bone fragments are small rounded, black concretionarylike objects, some of which appear to be the internal casts of crabs that have been rounded by current and wave action.

The Chonta formation along the Sarayaquillo River is abundantly fossiliferous. Pilsbry (1944) described four new species of gastropods from the Sarayaquillo Chonta collected by Singewald. On the basis of this small assemblage he concluded that the beds were higher Senonian than Coniacian; however, Knechtel who studied the ammonites considered this bed Coniacian.

Myriads of fossils occur throughout the Chonta formation in Cushabatay River area where the fauna is large and varied. Cephalopods are not abundant or diverse, pelecypods and gastropods dominate the assemblage. There is a large fauna of

minute gastropods including at least eight genera. The only braciopod in the fauna is *Lingula* which, however, is more or less abundant in the black shales. Fossil crabs are abundant. The rounded internal casts of crabs are profuse and show clearly the origin of some of the concretionarylike objects found in the Contamana Mountains and the Sarayaquillo sections. Echinoids occur at several horizons. Numerous Bryozoa, fish teeth, bone fragments, fish vertebrae, and worm borings complete this fauna.

Singewald (Knechtel, Richards, and Rathbun, 1947) collected the following species along the Cushabatay River and one of its tributaries, the Agua Blanca:

Tissotia steinmanni Lisson
Tissotia reesideana Knechtel
Tissotia singewaldi Knechtel
Tissotia waltheri Knechtel
Tissotia compressa Knechtel
Tissotia compressa var. *levis* Knechtel
Tissotia stephensoni Knechtel
Tissotia obesa Knechtel
Desmophyllites ellsworthi Knechtel
Lenticeras lissoni Knechtel
Eulophoceras berryi Knechtel
Heterotissotia lissoni Knechtel
Pholadomya sp.
Cucullaea andersoni Richards
Cucullaea reesideana Richards
Fusinus sp. indet.

The Cushabatay section of the Chonta contains *Inoceramus labiatus* Schlotheim in the lower part and indicates that the lower part of the Chonta is Turonian in age, the upper part Coniacian. The Chonta in the Contamana Mountains is Coniacian in age.

The Chonta formation exposed along the Pachitea River is abundantly fossiliferous. The fauna collected by Moran and Fyfe has been studied by the late J. P. Smith, and the fauna collected by Singewald has been studied by Knechtel, Richards, and Rathbun (1947).

The Singewald collection of the Chonta fauna from the Pachitea is as follows:

Lenticeras gerhardti Knechtel
Lenticeras baltae Lisson
Tissotia andii Knechtel
Tissotia roscheni Knechtel
Tissotia obesa Knechtel
Tissotia halli Knechtel
Tissotia singewaldi Knechtel
Tissotia steinmanni Lisson
Buchiceras bilobatum Hyatt emend. Brüggen
Barroisiceras bruggeni Knechtel
Roudairia intermedia Brüggen
Plicatulopecten böhmi Neumann
Ostrea nicaisei Coquand
Lima ellsworthi Richards
Pholadomya quinuana Neumann
Cardium centralis Richards
Turritella sp. indet.
Hemiaster fourneli var. *obliquus* Brüggen
Tissotia auressensis Peron
Vascoceras ameirense Choffat

Smith identified the following forms from the Moran and Fyfe collection and also considered it as Coniacian (Moran and Fyfe, 1933).

Coelopoceras lassali Brüggen
Lenticeras Andii Gabb
Cardium pulchrum Brüggen
Liopistha aff. *Molli* Coquand
Roudairea intermedia Brüggen
Ostrea nicaisei Coquand
Lima shortani Brüggen
Cucullea maresi Coquand
Hemiaster fourneli Desh
Hemiaster Steinmanni Neumann
Tissotia fourneli Bayle
Natica lassali Brüggen
Buchiceras bilobatum Hyatt
Puzosia? *guadama* Forbes
Plicatulopecten ferryi Coquand
Turritella spindet
Natica sp.
Lima grenieri Coquand
Paralenticeras Sierverei Gerhardt

Some of these fossils are classified by Steinmann as typical of the Turonian, as *Vascoceras ameirensi* Choffat and *Plicatulopecten ferryi* Coquand. Both these

species came from the lower part of the formation and suggest that the lower Chonta in the Pachitea region is Turonian in age. Moran and Fyfe correlated the Pachitea section with the Jumasha limestone (McLaughlin, 1924) of the high Andes. Lisson lists the following fossils as the most characteristic forms of the Jumasha limestone: *Tissotia fourneli* Bayle, *Hemiaster fourneli* Desh, *Ostrea nicaisei* Coquand.

Chase considered the Tambo limestone along the Perené River as Medial Cretaceous passing slightly into the Late Cretaceous. He correlated the Tambo with the Machay limestone of the Andes and with the Cretaceous shale and limestone series of Singewald.

Oliveira and Leonardos (1943) correlated the Chonta in the Territory of Acre with the Cretaceous shale and limestone series of Singewald and the Chonta formation of Moran and Fyfe. They list their Chonta as Albian to Coniacian but gave no fossil evidence.

The Chonta formation in the Pongo de Manseriche is Albian to Coniacian in age. The forms represented are as follows (Knechtel, Richards, and Rathbun, 1947).

Knemniceras attenuatum (Hyatt) Krause
Knemniceras attenuatum var. *spinosa* Sommermeier
Knemniceras semicostatum Sommermeier
Knemniceras crassicostatum Sommermeier
Knemniceras raimondi Lisson
Knemniceras crassinodosum Sommermeier
Knemniceras moorei Knechtel
Lyelliceras ulrichi Knechtel
Lyelliceras mathewsi Knechtel
Brancoceras sp. indet.
Oxitropidoceras douglasi Knechtel
Oxitropidoceras (*Manuaniceras*) *bosei* Knechtel
Oxitropidoceras (*Manuaniceras*) *carbonarium* Gabb
Oxitropidoceras (*Manuaniceras*) *hubbardi* Knechtel
Arca Knechteli Richards
Arca megumbona Richards
Inoceramus concentricus Parkinson
Exogyra n. sp. aff. *E. africana* Coquand
Nucula pongensis Richards
Protocardia n. sp. aff. *P. hillana* (Sowerby)
Protocardia meridionalis Richards
Paphia peruana Richards
Epitonium pongensis Richards
Plicatula singewaldi Richards
Pholadomya pongensis Richards
Liopistha sp. aff. *L. gigantia* Sowerby

The above forms are Albian in age. The only Coniacian form is *Tissotia reesideana* Knechtel.

The Napo limestone of eastern Ecuador is Aptian through Turonian. Tschopp lists the following fossils from the Napo: *Trigonia hondaana*, *Trigonia subcrenulata*, *Columbiceras*, *Knemniceras* cf. *attenuatum*—Aptian; *Oxitropidoceras*, *Brancoceras*, *Inoceramus concentricus*—Albian; *Inoceramus labiatus*, *Coelopoceras*, *Pecten*, *Exogyra*—Turonian.

VIVIAN FORMATION

Definition.—The Vivian formation is a yellow-brown to white, coarse- to fine-grained, cross-bedded sandstone, with interbedded black shale beds. It overlies the Chonta formation and underlies the Cachiyacu formation, both contacts apparently conformable. Most contacts between the Vivian formation and the Cachiyacu formation are fault contacts or are poorly exposed. The Vivian is easily recognized because it forms the outermost scarp surrounding geologic structures in the Contamana region. The formation was named by the Comisión Geológica after the Quebrada Vivian in the Vivian anticline of the Contamana Mountains.

Distribution and thickness.—The Vivian formation is well exposed in the Contamana

region. From the Canchahuayo anticline to the Sur anticline the Vivian has been studied extensively. In the Canchahuayo anticline the Vivian averages 140 meters; slightly smaller amounts were measured on the east side of the structure. Along Quebrada Huaya 132 meters was measured. In Quebrada Ponaza in the Central anticline 197 meters of the Vivian is exposed. West of the Ucayali River in the Santa Clara anticline 160 meters of Vivian crops out. In the Ventanilla Mountains, due east of the Santa Clara anticline, the Vivian formation is 315 meters. Along Quebrada Yanayacu, at the foot of Cerro Paco, and along the Cushabatay River the Vivian is 220 meters thick.

South of the Contamana region, along the Pachitea River, the Vivian formation has been studied by Singewald (1928), Moran and Fyfe (1933), and Heim (1947). Singewald correlated this rock unit with the Huacanqui sandstone on the Pongo de Manseriche but gave no estimate of its total thickness. Moran and Fyfe found the Vivian to be 160 meters thick and referred to this unit as the Sugar sandstone. Heim records 400 to 500 meters for the thickness of the Vivian formation in Ganzo Azul. Along the Perené River Chase (1933) records some 500 feet (165 meters) for his "basal sandstone", which is probably the Vivian equivalent in that area.

The Vivian in the Territory of Acre has been studied by Moura and Wanderley (1938) and Oppenheim (1937). Oppenheim described this unit as the Sungaru sandstone and found it approximately 150 meters thick. Moura and Wanderley called the same unit the "arenito do Divisor" and likewise placed its thickness at 150 meters.

Very little information is available on the Huallaga River region. The Vivian is probably equivalent to the "Primer grupo" of Valverde (1931), which is 300 meters. Singewald (1927) does not mention the thickness of the Huacanqui sandstone along the Pongo de Manseriche, but his map and cross section show it to be approximately 100 meters. Close to the Peruvian-Ecuadorian border in the Sierra de Cutucú, Oppenheim (1943) found the Vivian to be 150 meters.

Stratigraphic and lithologic features.—East of the Ucayali River in the Contamana Mountains the Vivian formation is almost entirely coarse white and yellow-brown sandstone, with a few zones of thin-bedded laminated sandstone and some black shale beds. The sandstone is fine- to coarse-grained and contains abundant quartz pebbles. The laminated units contain plant fragments and mica flakes. In the landslide material on the east side of the Canchahuayo anticline where the Ucayali swings in against the mountains, between Petronilla and Canchahuayo, the laminated beds are well exposed and contain an excellent plant flora. The laminated beds were not seen along Quebrada Huaya or Agua Caliente. An excellent exposure of the Vivian crops out along Quebrada Ponaza in the Central anticline. In this section the lower 35 meters consists of blue-gray silty shale containing mica flakes and plant fragments. The underlying Chonta is identical in lithology but lacks the plant fragments and the mica flakes. The Chonta contains bone fragments and crabs. The sequence here seems to show continuous deposition. The rest of the section along Quebrada Ponaza contains abundant zones of laminated beds interbedded with cross-bedded sandstone units. The absence of the shale and laminated zones in some of the Vivian sections is due to poor outcropping of these units.

West of the Ucayali River the Vivian formation is more shaly. In the Ventanilla Mountains it has a 50-meter black shale unit in the center. The black shale is silty and contains laminae of white siltstone in places. There are also interbedded units of iron-stained siltstone. This shaly zone contains numerous fossil plants. The beds above and below the member are white to yellow-brown, massive, cross-bedded sandstone. These units are prominent ridge makers, forming high scarps on each side of the river.

The Vivian formation is well exposed in the canyon of the Cushabatay River, just above where the Huchpayacu River enters the Cushabatay. It is divisible into two distinct facies. The upper part is white and yellow-brown, massive to shaly, coarse- to fine-grained sandstone with black shale partings and interbedded black silty shale beds. The black shale is hard and silty; many beds are up to 2 meters thick. It also contains numerous plant fragments, mica flakes, fossil wood, and detrital bone fragments, usually well rounded. This upper unit is 80 meters thick. Underlying the shale and sandstone member is 140 meters of massive, coarse, cross-bedded sandstone. The sandstone contains numerous iron concretions in the form of thin sheets on bedding planes or cross laminations, or in isolated irregular to rounded concretions. The unit is very hard and competent. The Cushabatay River has cut beautiful exposures through the lower Vivian formation. There has been extensive landsliding in the upper Vivian on the black shales.

Correlation.—No diagnostic fossils have been found in the Vivian formation. A collection of plant fossils from the Vivian collected at Petronilla, Cerro de Canchahuayo, on the Ucayali River was sent to R. W. Brown of the United States National Museum. He reported that fragments of monocotelydonous and dicotyledonous leaves are present but cannot be identified definitely. In the Contamana region the Vivian overlies the Chonta with apparent conformity; it appears to be transitional with the Chonta in Quebrada Ponaza in the Central anticline of the Contamana Mountains. The Vivian is overlain conformably by the Cachiyacu formation which is considered Upper Cretaceous. On the basis of stratigraphic position the Vivian appears to be Upper Cretaceous.

CACHIYACU FORMATION

Definition.—The Cachiyacu formation is a series of black shales, marly clay beds, and siltstones containing a brackish-water to marine fauna. It overlies the Vivian and underlies the Contamana group red beds with apparent conformity. The Cachiyacu is the Cretaceous part of the thick red beds (Puca facies) so extensively developed in eastern Peru. The name is derived from the fine sequence of post-Vivian beds measured by Newell along Cachiyacu Creek, east of the Ucayali River.

Distribution and thickness.—In the literature only vague references are made to this facies at the bottom of the thick red bed sequence and overlying the Vivian formation. Along the east slope of the Contamana Mountains the Cachiyacu is approximately 150 meters and is more or less the same thickness along the Cushabatay River west of the Ucayali River. In the Pachitea region Singewald (1928) described 100 feet or less of beds just above the Vivian formation that are thought to belong

to the Cachiyacu formation. Likewise Chase (1933) reports that the Tambo limestone and the Cascada red beds are gradational which suggests the presence of the Cachiyacu.

In eastern Ecuador the Napo is overlain directly by several hundred to 1000 meters of red beds, called the Tena formation, which contains marine fossils of Cretaceous age in the lower part (Tschopp, 1945). The Cachiyacu formation is probably correlative with at least the lower part of the Tena formation (Fig. 8b).

Correlation.—The Cushabatay locality yielded abundant nondiagnostic oysters perfectly preserved. The Cachiyacu section measured by Newell yielded *Ostrea*, ostracods, fish teeth, and small gastropods. Dr. J. B. Reeside of the United States National Museum studied some of the fossils from the Cachiyacu formation exposed around the mouth of Agua Cliente Canyon; he reports:

"*Pleurocera* sp. cf. Douglas (cf. also '*Pseudoglauconia*' *studeri* (Vilanova)) var. *peruana* Fritzsche is a fresh water form related to *Melania*. Douglas describes it as the most abundant form in the red beds in the Marcapata Valley of southern Peru and calls attention to its relationships with Fritzsche's *Pseudoglauconia* (an invalid name). Fritzsche ascribes his species to the Lower Cretaceous, but a check is certainly needed."

The oysters and nondiagnostic sharks' teeth both suggest marine or brackish-water conditions. The ostracods have been identified as *Cypris* and *Metacypris*, the latter of Cretaceous age, by Mr. A. D. Brixey.

Pilsbry (1944) identified several Cretaceous gastropods from station 15, collection 40, opposite Isla de Chonta, of the Singewald collection, which are considered by the writer to be in the Cachiyacu formation. He significantly mentions that they came from beds "possibly transitional to the Red Beds." The small fauna includes species of *Gyrodes* which according to Pilsbry are rather closely related to some forms described from the Quiriquina beds of Concepción Bay, Chile, which are considered, on the evidence of the ammonites, to be Maestrichtian. Pilsbry's list includes: *Gyrodes pachiteanus* Pilsbry, *Gyrodes singewaldi* Pilsbry, *Gyrodes* aff. *darweni* Philippi, "*Pleurotomaria*" (?) sp. indet.

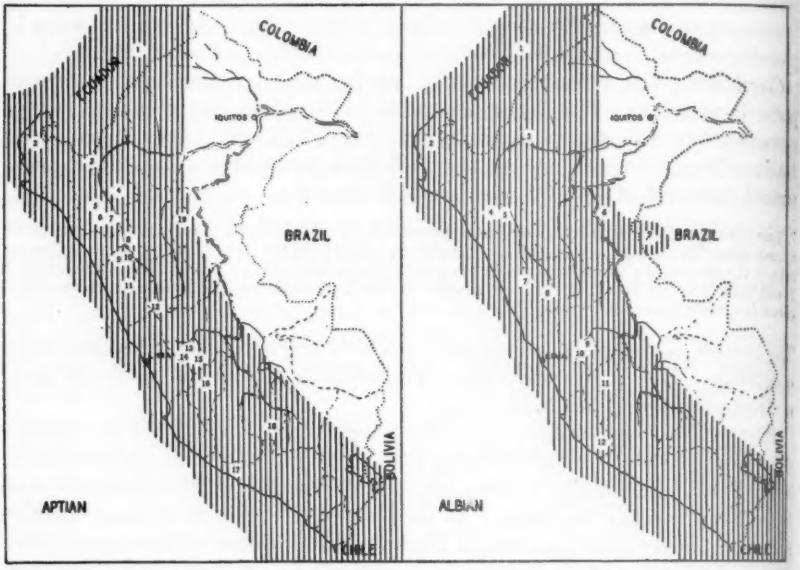
On the basis of this meager faunal evidence it is suggested that the Cachiyacu formation is Upper Cretaceous.

CRETACEOUS HISTORY

The Cretaceous rocks of the Contamana region show complex transgressive and regressive relations, because of their position on the edge of the Cretaceous geosyncline. Four times the sea encroached upon the area. Except for the coastal region, early Cretaceous deposits in Peru consist of hundreds of meters of coarse, cross-bedded sandstones with interbedded shale and contain coal in places. In the vicinity of Lima interbedded clay-shale and fine-grained sandstone of the Puente Inga formation contains ammonites of Early Valanginian age. These are overlain by 1000 meters of marine and continental shales and sandstone, the Salta de Fraile formation, in which the plant fossils and ammonites probably are Late Valanginian or Hauterivian. In numerous places in the high Andes the lowest Cretaceous consists of thick sequences of sandstone and dark shale containing fossil plants of Valanginian and Hauterivian age.

During the Barremian there was increased downwarping with brackish-water and marine limestones laid down in a trough which extended eastward as far as Huanuco.

As evidenced in the Cushabatay member and the Hollin sandstone Early Cretaceous time in eastern Peru and Ecuador began with depositions of coarse sands from



A B

FIGURE 6.—*Aptian and Albian fossil localities in eastern Peru and Ecuador*

the Brazilian shield. The sediments were deposited over a peneplaned surface in a fluvial environment.

The Aptian sea became widespread throughout the Cordilleran area and reached east of the Cushabatay Mountains, depositing the Esperanza member of the Oriente formation in this area (Fig. 6a). A shoreward facies of this transgression is represented by the Aguanuya member in the Cushabatay Mountains and the Raya member in the Contamana Mountains. This eastward transgression may have extended into the Territory of Acre, Brazil, through an embayment south of the Contamana and Contaya mountains, but specific data are not available on this area. In northern Peru and eastern Ecuador the Aptian sea deposited limestones and shales. The Peruvian geosyncline was connected with the Columbian geosyncline from Aptian to Turonian time. The Aptian in the geosyncline region of the Peruvian Cordilleras, west of the Contamana region, is about 150 meters of black, blue, and yellow limestone with some interbedded calcareous shales, abundantly fossiliferous. Probably in about late Aptian the sea receded from the Contamana region with the deposition of the upper Raya member and the Paco member, followed by the deposition of the Agua Caliente sandstone. A rejuvenation of the source area to the east supplied the coarse sand for the Agua Caliente member.

The Albian sea spread throughout Peru at least as far as in the Aptian (Fig. 6b)[2]. In the Contamana region the Albian sea encroached for a very short interval during the early Huaya, depositing marine shales and sandstones which contain ammonites, pelecypods, and gastropods. The Albian in this area is chiefly represented by non-

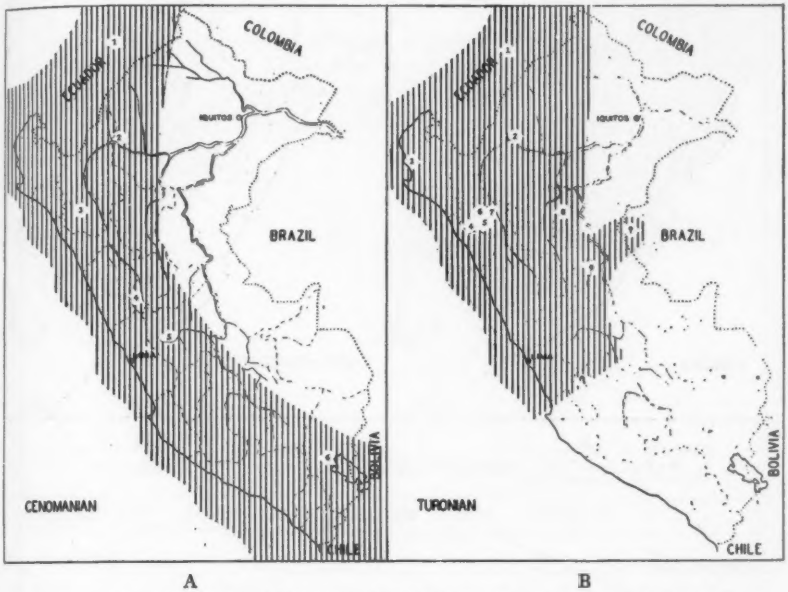


FIGURE 7.—*Cenomanian and Turonian fossil localities in eastern Peru and Ecuador*

marine sandstones and laminated sandstones and shales. A marine embayment may have existed south of the Contamana and Contaya mountains, extending into Brazil. The Albian sea spread over the area of Pongo de Manseriche and eastern Ecuador. The sea receded from the Contamana region at the close of the Albian, with deposition of sandstone and laminated shale beds of the Huaya. The Albian of the deeper geosynclinal area consists of 200 meters of alternating dark-gray to black bituminous shales, clay-shales, and siliceous limestones, called the Carahuacra formation (Weaver, 1942).

Cenomanian marine deposits in the Cordilleran region consists largely of yellowish-brown to dark-gray marly limestone with local interbedded sandstone layers (Fig. 7a). They have been named the Yamaluc formation in Central Peru (Weaver, 1942) and average about 100 meters. Cenomanian fossils have not been reported from eastern Peru or Ecuador. However, absence of Cenomanian records in northeastern Peru and eastern Ecuador may be due to accidents of collecting. The Cenomanian in the Contamana region is thought to be represented by the continental sandstones and shales of the upper Huaya.

[2] The reader should consult the paleogeographic maps by Weeks (1947) for a summary and broader picture of the distribution of the Cretaceous in all South America. Weeks shows islands and peninsulas in Peru during the Cretaceous; the author is not familiar with the data upon which these were based.

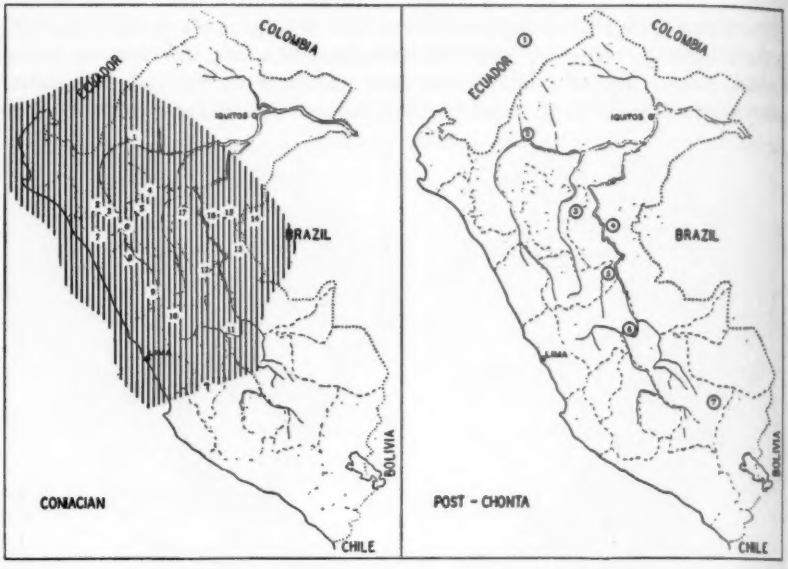


FIGURE 8.—*Upper Cretaceous fossil localities in eastern Peru and Ecuador*

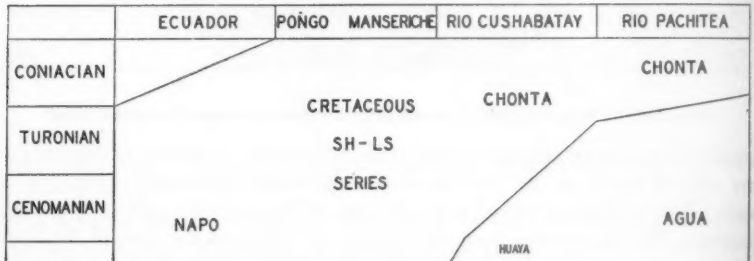


FIGURE 9.—*Time chart of Oriente and Chonta formations*

Little is known of the marine Turonian in Peru. It consists of about 50 meters of poorly stratified limestones which are for the most part very fossiliferous (Fig. 7b). The Napo limestone of eastern Ecuador includes Turonian in its upper part. In the Cushabatay and Pachitea regions Turonian forms are present in the lower Chonta and probably in the Pongo de Manseriche area. East of this line in the Contamana

region the Turonian is represented by the upper Huaya. Again there probably was a marine embayment south of the Contamana and Contaya mountains into western Brazil.

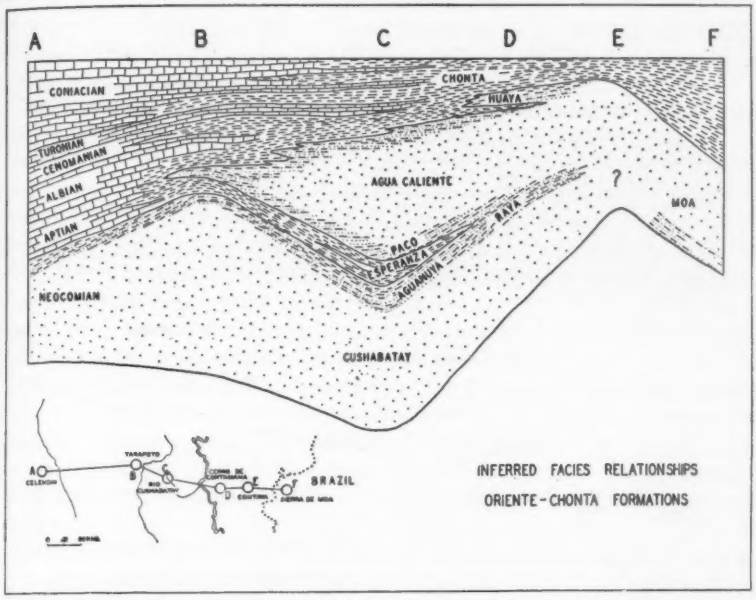


FIGURE 10.—*East-west facies relationships of Oriente and Chonta formations*

The marine Coniacian is very widespread throughout Peru (Fig. 8a). In the Santa Clara region it is represented in the Chonta formation from the Cordillera Oriental to Contaya, and it surely is represented in the upper part of the Rio Azul formation of western Brazil. The Chonta facies in this eastern area is shallow-water, predominantly fine-grained clastics with little calcareous sediment. The Coniacian in the high Andes is thick limestone and calcareous shales with subordinate dark clayey shale, and calcareous sandstone which attains a thickness of 500 meters in places. These units in the Cajamarca region have been named the Parobamba formation (Weaver, 1942). The Coniacian is not represented in the Napo formation of eastern Ecuador. The Peruvian geosyncline had become separated from the Columbian geosyncline to the north. Figures 9, 10, and 11 give a diagrammatic interpretation of the regional relationships of the Chonta and Oriente formation.

At the close of the Coniacian the seas receded from the Contamana region northwest toward the Amotape Mountains, where Middle and Upper Senonian marine sediments were deposited. In the Contamana region the receding Coniacian sea deposited the Vivian formation, interpreted as a regressive shore facies. In Medial Senonian time the sea encroached for the last time, extending into the Contamana region and depositing the Cachiyacu formation and also into the Pachitea and Perené

regions to the south, and northward into Ecuador (Fig. 8b). During the retreat of the sea in late Cretaceous the main geosynclinal region experienced an orogeny and uplift, reflected in the great sequence of red beds of the Lower Tertiary Contamana group which was deposited conformably on the Cachiyacu formation. This is the

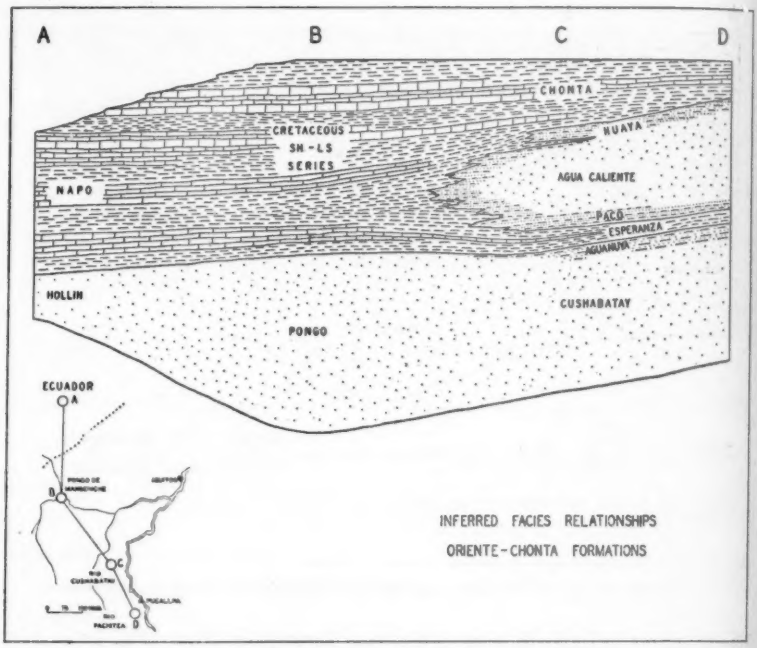


FIGURE 11.—*North-south facies relationships of Oriente and Chonta formations*

Peruvian orogeny of Steinmann (1929) and was confined to western Peru. The orogeny probably began immediately after the regression of the Chonta sea and continued slowly until post-Cachiyacu time when it seems to have increased in intensity. The thick and widespread sediments of the Contamana group are derived from these uplands. Orogeny probably continued through Early Tertiary time.

TERTIARY ROCKS

CONTAMANA GROUP

Definition.—Throughout the middle Ucayali River region the Cachiyacu formation is overlain by a thick series of predominantly red shales with interbedded units of sandstone, siltsone, and limestone. This rock series previously has been referred to as the "Red Beds" and the "Formación Puca" by Steinmann, Moran and Fyfe, Oppenheim, and others. Neither of these is an appropriate or formal formational name. The name Contamana group was adopted for this rock sequence by the

Comisión Geológica de la Montaña in 1943. The Contamana group overlies the Cachiyacu formation conformably and underlies the Ucayali formation with angular relationship. In the Pachitea region the upper part of the Contamana group is a thick section of reddish-brown clay shales, sandy shales, and sandstones called the Brown Beds by Singewald (1928). The Contamana group is the highest consolidated sedimentary formation found in this area and occupies the lowlands surrounding all geological structures which expose older formations.

Distribution and thickness.—In general, outcrops of the Contamana group are not well exposed and continuous. Due to the softness and great thickness of the group, very few complete measured sections are recorded. Newell in 1943 measured a complete section of the Contamana group along the Cachiyacu River between the Ucayali and the Contamana Mountains (Pl. 5). The measured thickness of the formation in this area is about 3000 meters. North of the Cachiyacu, on the flanks of the Canchahuayo anticline, the Contamana group is poorly exposed, and only 300 meters outcrops before being covered by alluvial deposits. Outcrops of the Contamana group are seen at various places along the Ucayali River, between Contamana and Orellana, especially between Canchahuayo and Orellana.

Along the Sarayaquillo River, outcrops of the Contamana group are sparse and scattered. No reliable information was obtained as to the stratigraphic sequence and structure. However, along the Cushabatay River, between the Ipururo and the Huchpayacu rivers, an excellent complete section is exposed. In this section the Contamana group is also about 3000 meters thick and is selected as the type section (Pl. 6).

In the frontier region of Peru-Brazil the red beds have been described and named the Cruzeiro formation by Oppenheim (1937). He found the Cruzeiro red beds exposed in the upper valley of the Jurua in Brazil and along the Tapiche, Contaya, Cashiboya, and Abujao rivers in Peru. However, he included no information as to the thickness of this formation in this region, and it probably includes Pliocene deposits. A Brazilian geological survey party worked in this area from 1936 to 1938 and described the Contamana group equivalents as the formação Puca (Oliveira and Leonardos, 1943) which is apparently very thin in this region.

South of the region under study along the Pachitea River Singewald (1928) found the Contamana group to be 1000 meters thick. Moran and Fyfe (1933), working in the same area, record about 1500 meters. Along the Perené River is about 4000 feet (1300 meters) of Contamana group equivalents (Chase, 1933).

West of the Contamana region in the valley of the Huallaga River Valverde (1931) describes 7000 meters of red beds of late Cretaceous and Tertiary age. He mentions that this great thickness may be due to faulting or folding and that 4000 meters is a more probable figure.

In the Pongo de Manseriche Singewald (1927) found the Contamana group to be about 2500 meters thick. Tschopp (1945) reported 4000 meters of dominantly red beds overlying the Napo formation in eastern Ecuador. The lower part, some 1000 meters or less thick and called the Tena formation, he placed in the Cretaceous. The upper 3000 meters is little understood and believed to be Tertiary in age. The various facies of this series have been named the Arajuno group, the Pastaza group,

the Ushpa group, the Chambira group, and the Curary group. This series as a whole has been named the "formación del Oriente".

Stratigraphic and lithologic features.—The Contamana group in the Cushabatay River region is divisible into five lithologic units; four of these are recognized in the Cachiyacu section east of the Ucayali River. The formations from top to bottom are the Ipururo, Chambira, Yahuarango, Casa Blanca and Huchpayacu; lithologic details of each formation are given in the stratigraphic sections.

Unfortunately previous students of the geology of the Peruvian Montaña made no attempts to study the Contamana group stratigraphically in detail or to measure accurate sections. All published reports deal only in generalities that are of little help in detailed correlation. The red beds of the Peruvian Montaña were first described in some detail by Singewald (1927) from exposures in the Pongo de Manseriche. He recognized three main divisions. The lower part consists of predominantly red sandstone with some interbedded red shale, overlain by an intermediate sequence of softer gray shales with thin intercalations of calcium carbonate and sandstone. The upper part of the Contamana group in the Pongo consists of red shale with but few thin sandstone intercalations.

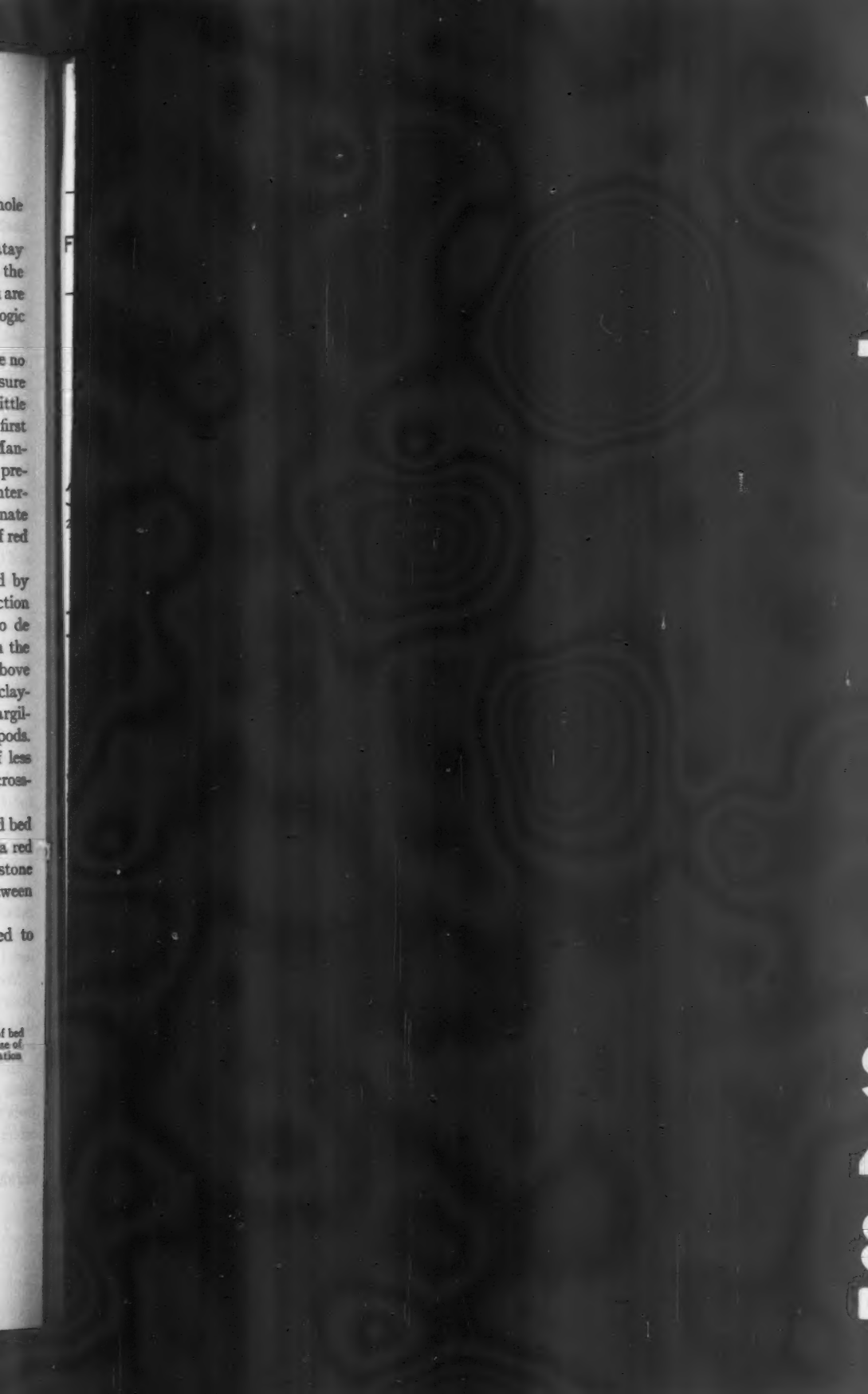
The Contamana group exposed along the Pachitea River has been studied by Singewald (1928) and Moran and Fyfe (1933). Singewald found the Pachitea section of the "Red Beds" to differ from those along the Marañon River in the Pongo de Manseriche. The Pachitea section lacks the sandstone that is so priminent in the upper part of the Pongo de Manseriche, and the intermediate gray shale beds above the Pongo. The Contamana group in the Pachitea region is dominantly red clay-shale, with beds of green shale and thin units of green to white, calcareous, argillaceous rock. These latter beds contain poorly preserved gastropods and pelecypods. Throughout the section are numerous beds of red and reddish-tan sandstone of less than 1 meter. The sandstone is fine-grained, argillaceous, massive, and cross-bedded.

South of the Pachitea region along the Perené River Chase (1933) called a red bed formation overlying the Tambo limestone the Cascada red beds. The Cascada red beds are composed of about 4000 feet of purple-red shales with interbedded limestone and sandstone. Chase classified the coarse sandstone (Vivian) which lies between the Tambo and the Cascada with the "red beds."

Stratigraphic sections.—The following sections have been carefully selected to illustrate the lithologic features of the Contamana group.

Cushabatay River section

	Thickness of bed in meters	Top of bed to base of formation
Upper Tertiary—Pliocene?—Ucayali formation		
Clay, black, brown, olive green, and variegated in color, with coarse yellow-brown, cross-bedded sand beds; in places associated with cobble and boulder conglomerates. Plants, wood, gastropods, and pelecypods in clay beds. Units are unconsolidated and flat-lying.....		25
Tertiary—Contamana Group (Eocene–Miocene) (Angular unconformity)		



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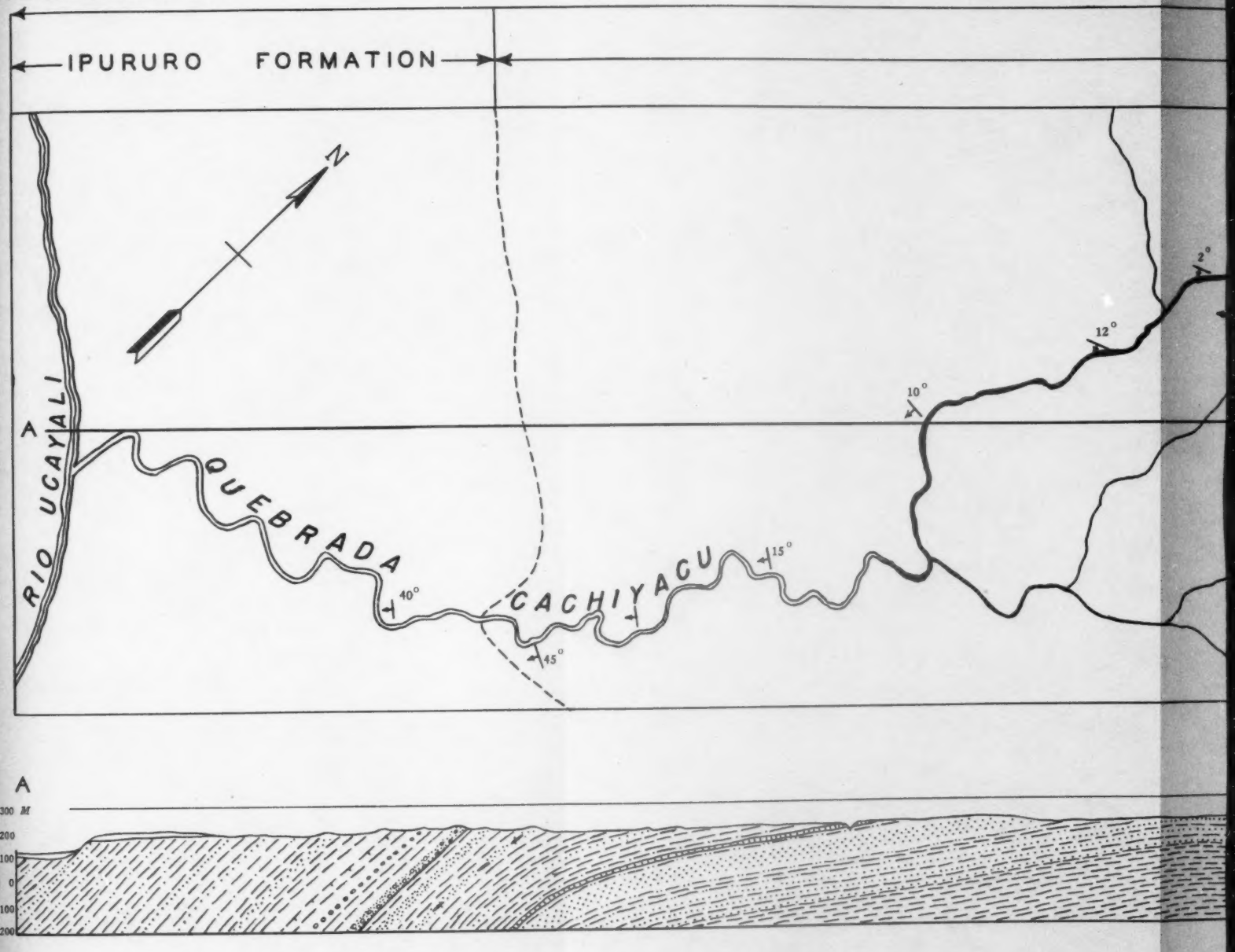
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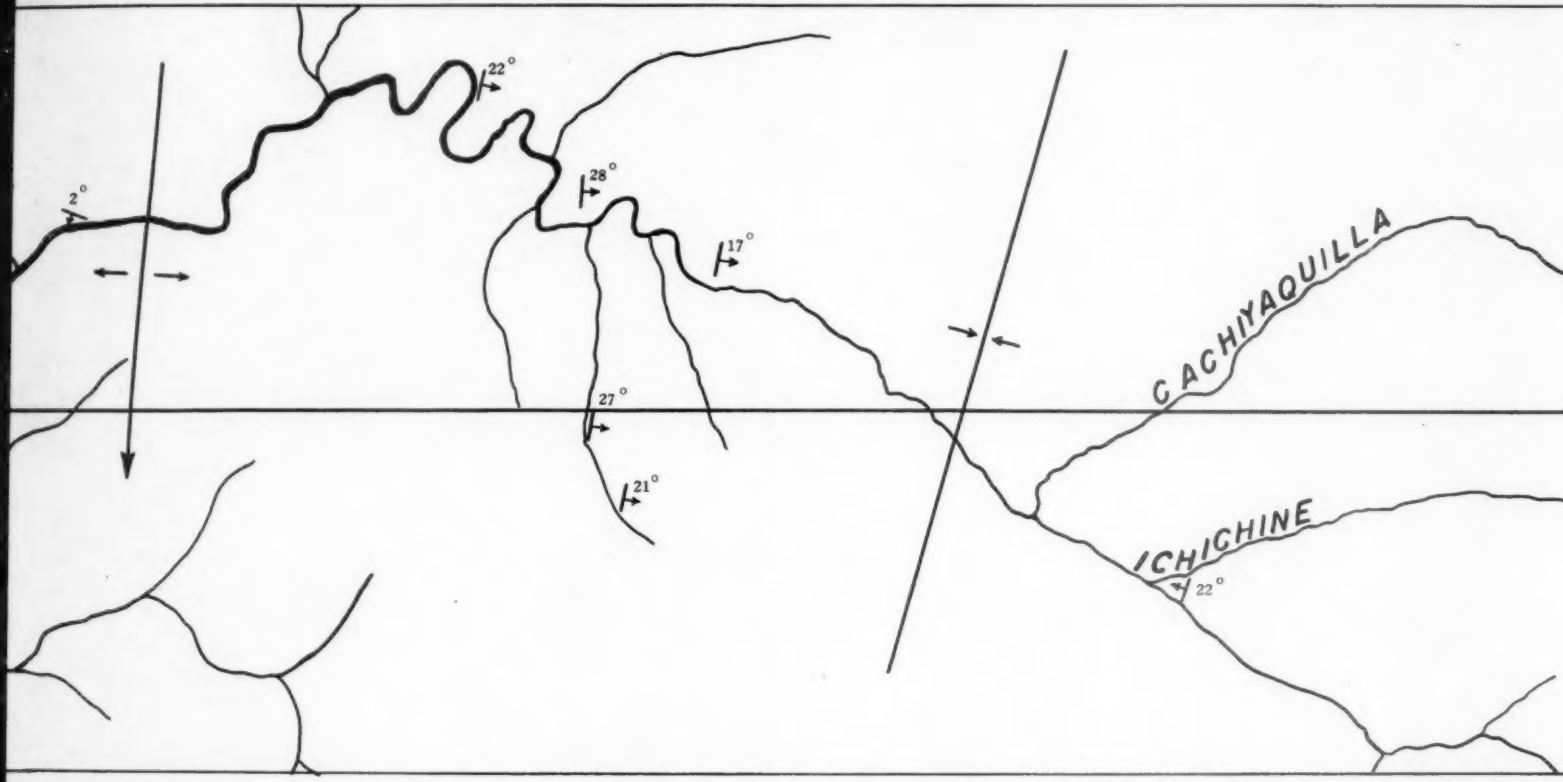
CONTAMANA GROU

CHAMBIRA FORMATION



SCALE

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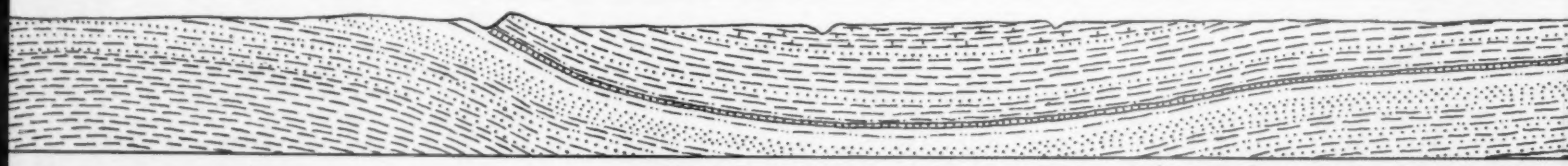
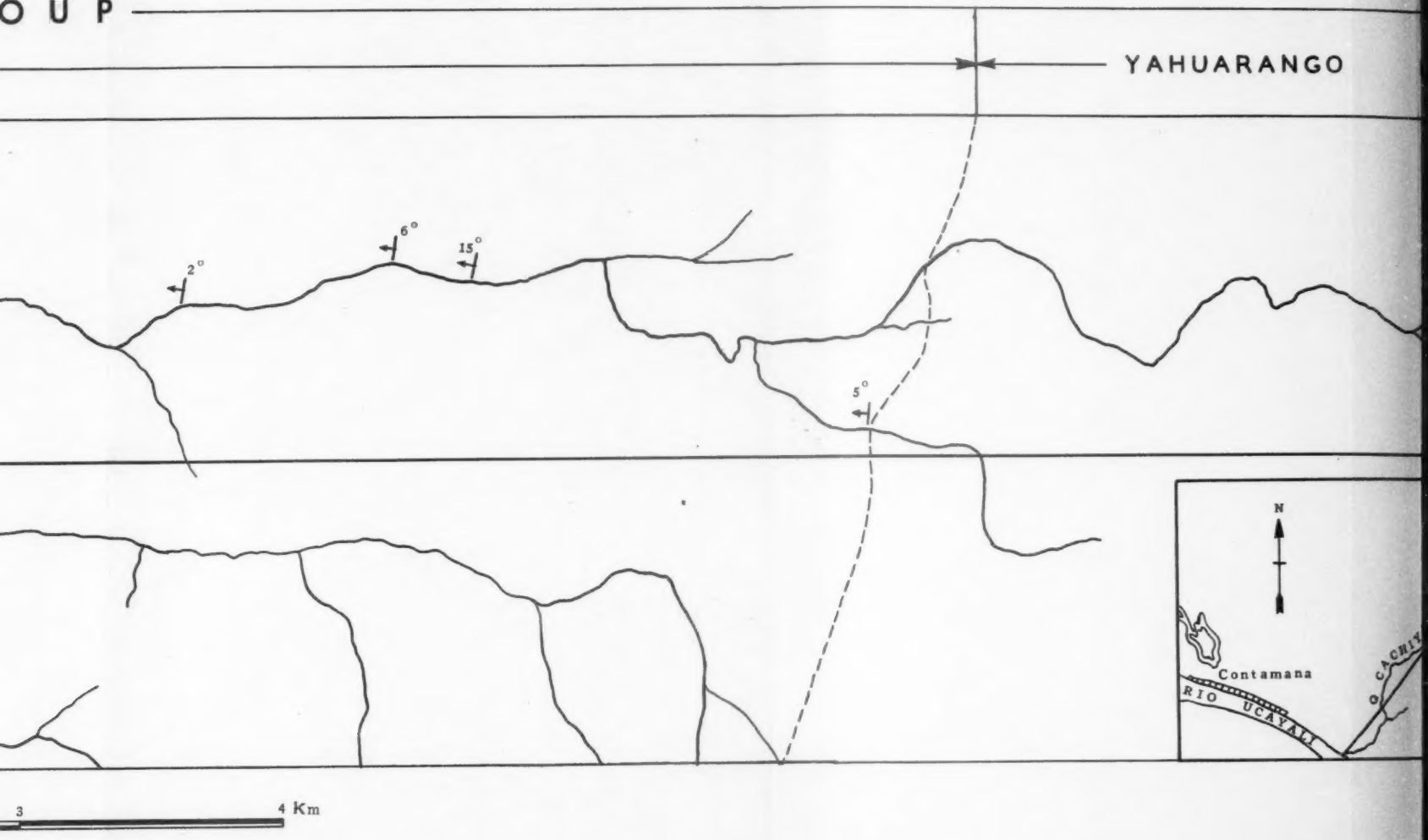


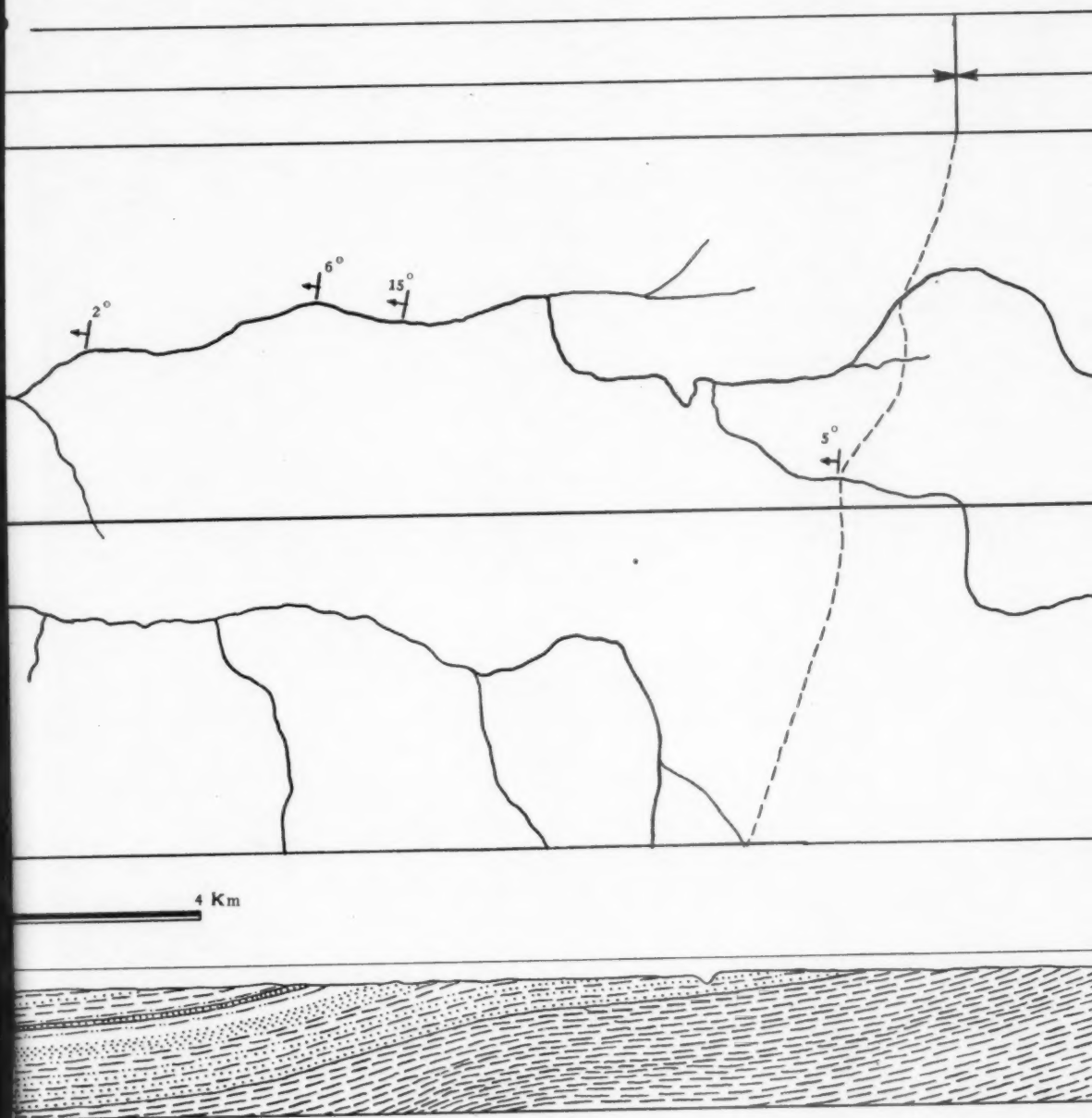
GEOLOGIC MAP OF QUEBRADA CACHIY

KCA - Cachiyacu formation, KV - Vivian formation, KCH - Chonta formation, KO -



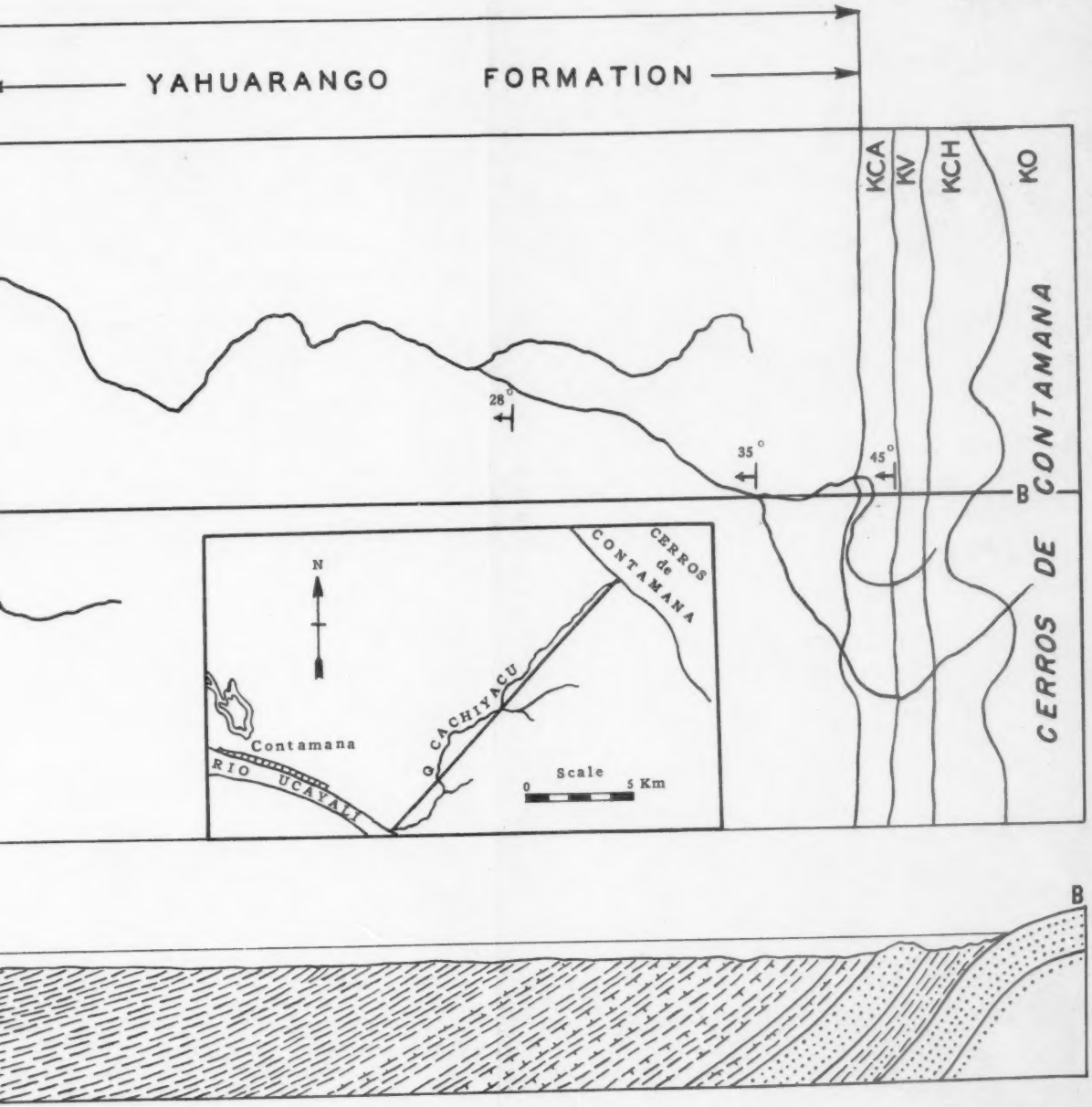
ACHIYACU

tion, KO - Oriente formation.



ACU

Oriente formation.


YAHUARANGO FORMATION
KCA
KV
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KO
CERROS DE CONTAMANA
28°
35°
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B
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Cushabatay River section—continued

	Thickness of bed in meters	Top of bed to base of formation
Ipururo formation		
16. Sandstone, gray brown, fine-grained, massive, and shaly in parts; weathers light gray on the surface; contains massive hard iron sandstone concretions, sandy clay beds and interbedded beds of clay-shale. Lower part of unit contains some red variegated shale beds. Fossil plants and small gastropods present	145	2963
15. Shale, red, variegated, silty and massive in places, with some interbedded units of red siltstone, gray clay-shale and siltstones; a few interbedded units of massive, coarse, cross-bedded white to reddish-brown sandstone; weathers a dark gray brown. The sandstone unit contains massive and large sandstone concretions, which range up to 2–3 meters in thickness and are tabular in shape	220	2818
14. Sandstone, gray brown, coarse- to fine-grained; contains lenticular concretions of hard quartzitic sandstone and isolated pebble conglomerate beds, one of which is close to the bottom of the unit and contains quartz and sandstone pebbles with some iron present; unit weathers in irregular pits. Sandstone has interbedded units of red shale in the form of thin shale partings 5 cm., and beds up to 8 meters; this unit is a prominent ridge maker	605	
Chambira formation		
13. Shale, red, silty in places, with a few interbedded beds of gray-brown, massive cross-bedded, fine-grained sandstone that has red shale partings. In places the sandstone contains small pebbles. Two of these interbedded sandstone beds toward the center of the member form prominent ridges; the red shale beds toward the bottom contain a thin unit of calcareous siltstone and pink limestone concretions	680	1903
Yahuarango formation		
12. Shale, red, silty, with interbedded units of red and gray siltstone; the lower part is gray-brown siltstone interbedded with red shale containing numerous fossil teeth, bones, plants, pelecypods, and pyrite concretions; fossils are of fresh-water type	80	1223
11. Shale, red, silty in parts, mostly covered	300	1143
10. Siltstone, brown, massive, contains numerous thin clay pebble beds; forms ridges; lower part contains some interbedded red shale beds	75	843
9. Shale, red, silty in parts, with interbedded beds of purple and black shale; also two marly limestone horizons present. The black shale beds contain numerous limestone concretions; the red and purple shales contain gypsum in beds up to 10 cm. and also in isolated patches. Some interbedded gray siltstone beds contain fossil plants, pelecypods, poorly preserved, and pyrite concretions	300	768
8. Siltstone, gray, with numerous iron concretions, giving a conglomeratic appearance on weathering; gypsum present; unit is hard and is a ridge former	10	468
7. Shale, red, with interbedded red siltstone and gray shale and siltstone beds	100	458
6. Conglomerate, pebbles rounded to semiangular, up to 10 mm. in diameter; cross-bedded and ripple-marked, very hard	10	358
5. Shale, red, silty in parts, with interbedded purple and gray silty shale beds	50	348
Casa Blanca formation		
4. Sandstone, white, massive, fine-grained, soft, with interbedded beds of black siltstone toward the bottom	60	298
Huchpayacu formation		
3. Shale, red, silty, in parts, with interbedded units of purple and gray shale and siltstone	167	238

Cushabatay River Section—continued

	Thickness of bed in meters	Top of bed to base of formation
2. Siltstone, gray, massive, calcareous; forms small scarp in river	1	71
1. Shale, red, with interbedded red and gray siltstone beds	70	70
Total	2963	

Cachiyacu section of the Contamana group

(The following section was measured by N. D. Newell, assisted by Isaac Tafur, in 1943. The divisions recognized by Newell have been modified to fit the author's proposed classification of the Contamana group.

Upper Tertiary (Ucayali formation, Pliocene?)

20. Sand and sandy clay, calcareous, buff and ash-colored, lies horizontally on tilted and truncated older beds, with basal contact about 20 meters above the normal level of the Ucayali River; forms terraces or flat upland along right bank of Ucayali near mouth of Cachiyacu Creek and is especially well developed around the mouth of Machira Creek, 5 kms. south of Cachiyacu	10–20	
Tertiary (Contamana group, Eocene–Miocene?) (Angular unconformity)		
Ipururo formation		
19. Clay and silt of gray, salmon pink, or lavender, interbedded with loose or friable, coarse quartz sand of well-rounded pebbles of vein quartz up to 2 cm., chalcedony up to 3 cm., and pebbles of hard sandstone of same dimensions; unfossiliferous; best shown in river bluffs between the Contamana cemetery and mouth of Cachiyacu Creek, where they dip steeply toward the Ucayali (SW.) at 35°–45°	800	3110
18. Sandstone, conglomeratic, brownish gray, resistant, ridge-forming unit, contains pebbles up to 6 cm. in diameter of buff quartzite, vein quartz, chalcedony, limestone, well shown in stream channel of Cachiyacu, forms top of series of hard, conglomeratic beds; dips 45° S. 30° W.	20	2310
17. Marly clay, variegated, brown, tan, and lavender, with one or more beds of pink and olive conglomeratic sandstone, containing pebbles of brown quartzite and balls of brown claystone	200	2290
16. Sandstone, conglomeratic, medium, olive to pink, arkosic, massive, with occasional beds of conglomerate containing pebbles of limestone, quartz, quartzite and clayballs up to 2 cm. in diameter; a few clay bands containing concretionary nodules of limestone up to 20 cms. across; forms base of conglomeratic sandstone series, dips 43° S. 35° W.	30	2090
Chambira formation		
15. Clay, marly, variegated gray and pink	40	2060
14. Sandstone, pink and brown, and intercalated marly variegated clays, dips 43° S. 30° W.	35	2020
13. Clay, marly, variegated	60	1985
12. Sandstone, pink and brown, heavily cross-bedded, contains a very few carbonized trunks of small trees; at base has 3 meters of pebbly red clay with pebbles of limestone up to 2 cm. containing carbonized fragments of plants and fossil bones	35	1925
11. Clay, marly, variegated, red gray, buff, at the base is a layer of concretions of brown limestone containing bone fragments (crocodile) and turriform snails	10	1890
10. Sandstone, greenish gray to pink, blocky, fine, contains a few thin laminae of lignite	20	1880
9. Mudstone, red and chocolate, silty	94	1860
8. Tuff, massive, nodular, light gray to greenish buff	2	1766

Cachiyacu section of the Contamana group—continued

	Thickness of bed in meters	Top of bed to base of formation
7. Mudstone, calcareous, chocolate, sandy	45	1764
6. Sandstone, massive, cliff former, cross-bedded, pink	70	1719
5. Clays, calcareous, maroon, and pink to white mudstone, silty	65	1649
4. Sandstone, pink, massive, and interbedded red massive mudstone	75	1584
Yahuarango formation		
3. Mudstone, red, massive, and a few red sandstones; at top is thin bed of light-gray clay 1–2 meters thick, filled with small irregular limestone concretions (Phosphate) about the size of coarse shot; contains snails, crab claws, turtle plates, and indeterminate fragments of bone and clams like *Anodonta*	879	1509
2. Clays, gray and red, calcareous, with minor amounts of red sandstone	615	630
1. Marl, gray, filled with charophytes, underlain by a few meters of red and gray marly clays and oölitic white limestone	15	15
Total	3110	

Correlation.—Fossils were found at several horizons in the Contamana group in the Cushabatay River area. These horizons are at 2900 meters (Ipururo formation), 1150, and 530 meters (Yahuarango formation) above the Cachiyacu formation. All of the fossils indicate fresh-water environment. In the Cachiyacu section Newell found fossils 1900 meters (Chambira formation), and 1500 and 10 meters (Yahuarango formation) above the Cachiyacu formation. They are all fresh-water forms. The lowest fossil horizon immediately above the Cachiyacu formation contained abundant plant oogonia (Charophytes) identified by Peck (1947) as Eocene forms. None of the other fossils found in the Contamana group in the Contamana region have been sufficiently well preserved or diagnostic to corroborate the determination.

In the Contamana group equivalents exposed along the Huallaga River, V. G. Richards found a jaw bone with well-preserved teeth (Anthony, 1924). The teeth are those of a perissodactyl, which Anthony placed in the Oligocene with doubt because of the lack of information about the formation from which they came.

Singewald (1928) found poorly preserved fossils in the Contamana group at a number of localities along the Pachitea River. The assemblages consist mostly of small ornate gastropods and pelecypods studied by H. A. Pilsbry (1944). Pilsbry recognizes *Mitriculis incarnum* Pilsbry of Eocene age from a horizon interpreted as just above the Cachiyacu formation. In higher horizons he identified the following forms which indicated upper Oligocene or Lower Miocene.

Pomacea manco Pilsbry
Hemisinus pictus Pilsbry
Hemiscus (*Longiverena*) *avus* Pilsbry
Mytilopsis singewaldi Pilsbry
Ostomya terminalis Pilsbry
Ostomya pachiteana Pilsbry
Corbula arcana Pilsbry

In the American Museum of Natural History there is a specimen (No. 1662) of a fossil turtle, *Podocnemis* from the Contamana group exposed along the Aguaytia River, west of the Ucayali River. Dr. H. R. Bassler assigns this form a Miocene age.

Throughout eastern Peru the folded Contamana group is overlain by flat-lying beds of Pliocene age. Along the Aguaytia River Berry (1925) identified plant fossils

from these flat-lying units, which he placed in the late Miocene or Pliocene with reserve because of a lack of a standard for comparison. Between the town of Iquitos and Tabatingo on the Amazon River the flat-lying Pebas beds, which contain a Pliocene fauna, crop out.

The Contamana group thus has yielded fossils of Eocene, Oligocene, and the Miocene age and is overlain by flat-lying Pliocene beds. The Eocene to Miocene age of the Contamana group is fairly certain but it is to be hoped that more stratigraphical information will accompany future fossil findings to facilitate the closer dating of the various formations.

INCAIC OROGENY

Toward the close of the Miocene the region was strongly folded and faulted. The folding affected most of the Andean region of Ecuador, Peru, and Bolivia (Tschopp, 1945; Steinmann, 1929; Newell, personal communication; Ahlfeld, 1946). The broad folding of the Contamana region produced high anticlinal hills extending well into the Serra do Môa region of western Brazil and westward to the Pacific. This folding was followed by a period of extremely rapid denudation (in places almost 3 miles of sediments must have been removed) and the formation of the Ucayali peneplane. This peneplane is overlain by flat-lying Pliocene beds.

LATE TERTIARY ROCKS

UCAYALI FORMATION

Throughout the Contamana region there are flat-lying alluvial deposits of late Tertiary and Quaternary age. Along the Ucayali, Sarayaquillo, and Cushabatay rivers, there are excellent exposures. The best outcrops are along the Cushabatay River, where clean banks up to 25 meters high expose black, brown, olive-green, and variegated clay beds and coarse cross-bedded sand beds. In many places lenses of cobbles and boulders are associated with the sand and clay beds. The clay beds contain numerous fragments of plants, wood, fresh-water gastropods, and pelecypods; all of the units are soft, unconsolidated, and flat-lying. Good exposures of these same units are present along the right bank of the Ucayali River near the mouth of Cachiyacu Creek and Machira Creek. They have been named the Ucayali formation and are tentatively considered Pliocene to recent in age.

IGNEOUS GEOLOGY

The only igneous rocks outcropping in the Contamana region are in Cerro Paco. High in Cerro Paco is a light- to dark-gray basic porphyry, with aligned euhedral to anhedral feldspar phenocrysts up to 1 inch long.

The porphyry is intruded into the Sarayaquillo formation. There is a small dike of the porphyry cutting the Sarayaquillo formation some distance from the main igneous mass. The porphyry includes numerous xenoliths of the Sarayaquillo formation and in places has altered the sandstone to a white quartzite. The age of the intrusion is not definitely known; however approaching Cerro Paco all the rock

formations around the southern end of Cerro Paco have steepened dips, including the Contamana group. The Oriente formation has dips up to 50°, and approaching the main body of the porphyry the sedimentary formations have been faulted and warped. Therefore the intrusion probably took place after the deposition of the Contamana group, in the Middle Tertiary, probably coinciding with the Incaic orogeny which formed the cerros in this region.

GEOLOGICAL STRUCTURES

GEOGRAPHIC RELATIONSHIPS

Within the Contamana region three northwest-trending structural provinces are recognized: (1) the Cordillera Oriental including the Cushabatay and Ventanilla mountains, (2) the Ucayali peneplane, and (3) the Contamana Mountains and the Contaya Dome. The Cordillera Oriental is by far the most prominent feature. The Contamana Mountains and Contaya are an outlying spur of the Cordillera Oriental surrounded by the red-bed plain. The dominant structural elements are folds; major faults apparently are confined to the Cordillera Oriental. Little is known of faulting east of the Cordillera Oriental. The intensity, breadth, and complexity of the folding is greatest in the Cordillera Oriental and diminishes eastward.

CORDILLERA ORIENTAL

Domes, anticlines, spurs, longitudinal faults, cross faults, and overthrusting are the major structural features of the Cordillera Oriental. Between Lat. 5°40′ and 6°20′ S. the front of the Cordillera Oriental is a fault bringing the Sarayaquillo formation against the Contamana group. The fault dips west and is flanked on both ends by two cross faults that join and cross the longitudinal fault at an obtuse angle. The cross faults appear to dip inward and the mass within the three confining faults has acted as a wedge bringing the Sarayaquillo formation eastward in contact with the Contamana group.

South of this unit the Tarapoto Dome lies between the Cainarache and Huallaga rivers. It is closed on the northwest by a fault in the Oriente formation. The north and south sides are flanked by a normal sequence of outward-dipping Chonta, Vivian, and Contamana group formations. Eastward it joins with the Cushabatay Mountains through continuous outcrops in the Oriente formation. Where the Huallaga breaks out of the Cordillera there is a northward-plunging fingerlike spur of Vivian sandstone with the upper Oriente formation exposed in its center.

A thrust fault trending parallel to the mountain some 10 kilometers east of San Martin—the Huallaga overthrust—brings the Sarayaquillo formation directly on the Contamana group. The Cordillera Oriental from north of Cachipuerto to the Huallaga is anticlinal, broken by the longitudinal fault above the Tarapoto Dome. The western flank, however, shows a normal southwesterly dipping sequence of the Contamana group, Vivian, and Chonta formations. This flank begins as the southern part of the Tarapoto Dome striking east-west and abruptly swings to the northwestward just beyond Chasuta. Upon this westerly flank the Huallaga over-

thrust has ridden. The overthrust appears to end north of Cachipuerto where it is cut by a cross fault trending N. 60° W. Midway between this point and San Martin the Huallaga overthrust is cut and displaced by a cross fault trending N. 40° E. South of the Huallaga River another northeast-trending fault appears to be composed of several related segments which have produced a zig-zag fault line. The displacement on this fault is very large as it brings to the surface Pennsylvanian limestone in contact with the Contamana group on the west. The southward extension of the Huallaga overthrust beyond the headwaters of the Cushabatay River is unknown.

Southeastward from the Huallaga River near Yarina a large spur or nose of the Cordillera Oriental forms the Cushabatay and Ventanilla mountains. The Cushabatay Mountains trend northward, curving westward in its northern part where it joins the Cordillera Oriental. It terminates in Cerro Paco just north of the Cushabatay River. The mountain is a southward-plunging anticline. The center of the anticline is occupied by the Sarayaquillo formation. The Cushabatay River occupies a syncline between the Cushabatay Mountains and the Cordillera Oriental. The only igneous rocks outcropping in the Contamana region is a basic porphyry intrusion in Cerro Paco. The Ventanilla Mountains are a curving southward fingerlike spur off the eastern flank of the Cushabatay Mountains. The range is anticlinal, and the central part is occupied by the Oriente formation which extends in continuous outcrop from the Cushabatay Mountains. The axial region of the Ventanilla Mountains is faulted. The range is separated from the Cushabatay Mountains in its southern part of a low embayment of the Chonta shales which are badly faulted and folded. The Vivian hogback extends around this large spur from the Huallaga to the Cushabatay River forming a continuous half circle and closing the two structural elements.

UCAYALI PENEPLANE

Beginning abruptly at the foot of the Cordillera Oriental and continuing eastward surrounding the Contamana and Contaya mountains is a vast, low, flat country underlain by the Contamana red beds. This broad flat topographic area is underlain by numerous anticlines and synclines, with some faulting. Little specific information is available on these structures. The aerial pictures do not show enough to define specific structures. However, by plotting trend lines formed by small scarps, changes in vegetation, etc., a rough structural pattern can be obtained. This has great value in concentrating the area of field studies to the more fruitful regions. Another factor that adds to the difficulty of working in the red beds is the general scarcity of good outcrops. The traverse along the Sarayaquillo River showed a series of anticlines, synclines, and some faults, but the outcrops are so sparse one could not be sure that the structure was properly outlined. Close to the Ucayali River and its larger tributaries the Contamana group is usually covered by alluvial deposits.

The Santa Clara anticline is the only structure in this plain country in which units older than the Contamana group outcrop in its center. The Santa Clara structure is an arcuate northwest-trending anticline exposing Huaya beds in its center. It is 8 kilometers long and 5 kilometers wide.

East of the town of Contamana and west of the Contamana Mountains the Cachiyacu anticline, a deep-seated structure in the Contamana group, is in almost direct structural alignment with the Santa Clara anticline to the northwest. Most of the folds and anticlines within the Contamana group parallel the larger folded elements in the region. Probably there are other anticlinal structures along the west flank of the Contamana Mountains.

CONTAMANA AND CONTAYA MOUNTAINS

The Contamana Mountains are an elongated slender anticlinal structure extending from slightly north of Petronilla, on the Ucayali, southeastward to Lat. 7°30′ S. The anticline is asymmetrical with steep dips on the west. The center of the anticline is occupied by the Oriente formation. The western flank has dips up to 60°–70° and is faulted with the Contamana group in places. The exact extent and details of this fault are as yet not completely understood; however, the displacement is small. Within this structural unit there are seven closed anticlines. The closures take place within units of the Oriente formation. In the Sur and Central anticlines the Cushabatay member is exposed, in the Intermedio, upper Agua Caliente, in the Canchahuayo anticline, the lower Agua Caliente member, in Este anticline, the lower Huaya member, in the Vivian anticline, the upper Huaya member, and in the small unnamed anticline north of Canchahuayo, the Huaya member. These closed anticlines are not in one continuous alignment. The Canchahuayo anticline plunges toward the Ucayali River above Petronilla and trends southeast in a line including the Intermedio and Central anticlines. Each two anticlines are separated by a low saddle. The Central anticline plunges south-southeast at Agua Caliente canyon and indicates an alignment with the Cachiyacu syncline to the south. The Sur anticline begins just north of Quebrada Cashiboya and plunges north-northwest at Agua Caliente, just east of the southern end of the Central anticline, lines itself with the syncline between the Central and Este anticlines, and extends to the small unnamed anticline north of the Canchahuayo anticline. The Este anticline lies by itself parallel to and east of the above structural lines. Likewise, the Vivian anticline, trending north, lies east of the other two lines and is by itself.

A southward-plunging syncline of the Contamana group separates the Contamana and Contaya mountains. Across the northern part a continuous band of the Vivian formation extends from one structure to the other. The area is mostly low and swampy. The Contaya Dome is a low broad structure exposing Ordovician rocks in its center. The Vivian, Chonta, and Oriente formations form a circle of outward-dipping scarps. Unfortunately field surveys were never made in the Contaya region, and numerous key problems of the structure and especially stratigraphy remain unsolved.

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UCSF

SARAYAQUILLO FORMATION

Oc

ORIENTE FORMATION

Oa | Oe | Op | Oac | Oh

CHONTA FORMATION

Q. Yanayacu

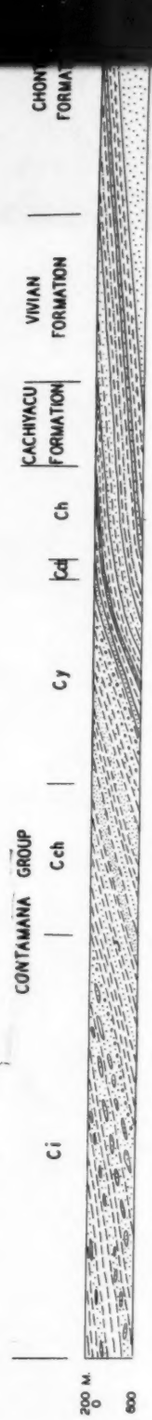
Q Porfidio

QUEBRADA PORFIDIO

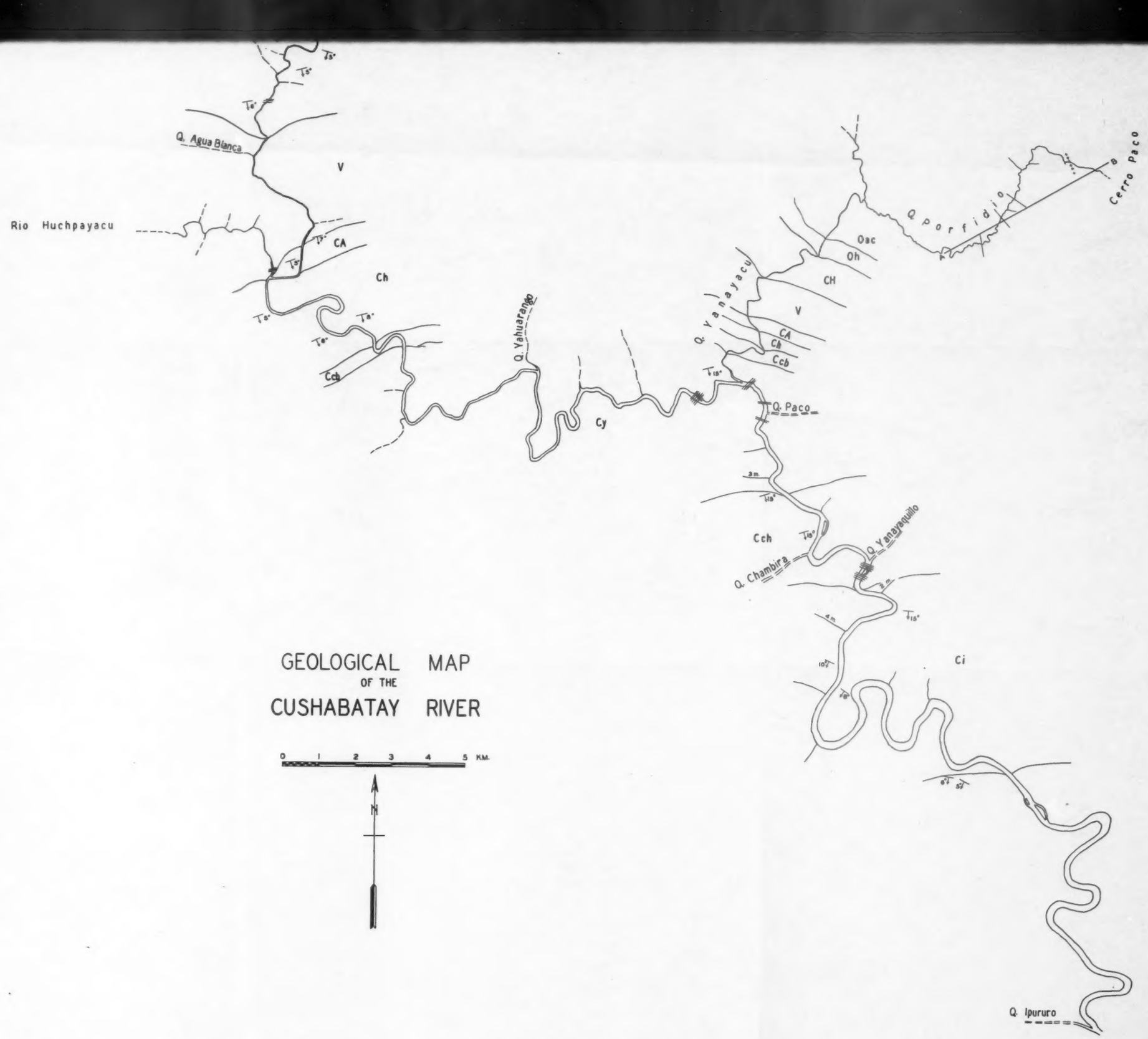
Q. Aguanuya

Q. Agua Blanca

Paco



GEOLOGICAL MAP OF THE CUSHABATAY RIVER



GEOLOGIC MAP OF CUSHABATAY RIVER

O - Oriente formation, S - Sarayaquillo formation, Ci - Ipurure formation, Cch - Chambira formation, Cy - Yahuarango formation, Ccb - Casa Blanca formation, Ch - Huchpayacu formation, Oh - Huaya member, Oac - Agua Caliente member, Op - Paco member, Oe - Esperanza member, Oa - Aguanuya member, Oc - Cushabatay member.

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Inset map shows area covered by geologic map compared with State of Pennsylvania at same scale.

Cretaceous and Tertiary formations of eastern Peru and Ecuador.

a. Known areas of Ordovician rocks in eastern Peru and Ecuador (After Newell and Tafur, 1944).

b. Known areas of Upper Paleozoic rocks in eastern Peru and Ecuador.

Shaded portion represents extent of marine invasion.

a. Aptian localities: 1. Eastern Ecuador, 2. Cordillera de Amotape, 3. Rio Chinchipe, 4. Valle de Utcubamba, 5. Hualgoyoc, 6. Cajamarca, 7. Celendín, 8. Patás, 9. Corongo, 10. Sihuas, 11. Carhuás, 12. La Union, 13. Tarma, 14. Yauli, 15. Huancayo, 16. Huancavelica, 17. Chala, 18. Chuquibambilla, 19. Rio Cushabatay.

b. Albian localities: 1. Eastern Ecuador, 2. Cordillera de Amotape, 3. Pongo de Manseriche, 4. Cajamarca, 5. Celendín, 6. Cerros de Contamana, 7. Pariahuanca, 8. Huallanca, 9. Tarma, 10. Yauli, 11. Huancavelica, 12. San Javier.

Shaded portion represents extent of marine invasion.

a. Cenomanian localities: 1. Rio Napo, 2. Pongo de Manseriche, 3. Cajamarca, 4. Ambes and Huambos, 5. Tarma, 6. Ayabacas.

b. Turonian localities: 1. Rio Napo, 2. Pongo de Manseriche, 3. Playa Tortugas, 4. Tembladera, 5. Cajamarca, 6. Chota, 7. Celendín, Rio Cushabatay, 9. Rio Pachitea.

Shaded portion represents extent of marine invasion.

a. Coniacian localities: 1. Pongo de Manseriche, 2. Hualgayoc, 3. Celendín, 4. Moyabamba, 5. Huancayo, 6. Bambamarca, 7. Otusco, 8. Sihuas, 9. Huallanca, 10. Cerro de Pasco, 11. Rio Tambo, 12. Rio Pachitea, 13. Rio Abujao, 14. Território do Acre, 15. Contaya, 16. Cerros de Contamana, 17. Rio Cushabatay.

b. Post Chonta Cretaceous localities: 1. Eastern Ecuador, 2. Pongo de Manseriche, 3. Rio Cushabatay, 4. Cerros de Contamana, 5. Rio Pachitea, 6. Rio Perené, 7. Marcapata Valley.

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LAVA MOVEMENT AT PARÍCUTIN VOLCANO, MEXICO

BY KONRAD B. KRAUSKOPF

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ABSTRACT

The lava flows of Parícutin Volcano, Mexico, offer an exceptional opportunity to study details of lava movement, because many flows are accessible throughout their length and can be watched from their birth to the cessation of their movement. Petrographically the lavas show no significant difference from one flow to another or in different parts of the same flow. The maximum lava temperature observed was 1070°C.; the maximum estimated rate of flow was 60 meters per minute; the viscosity is probably on the order of 10^5 to 10^6 poises. The flows start in fissure zones cutting older Parícutin lavas near the southwest base of the volcano. Within a short distance of its orifice a flow is covered with cooled blocks which are broken and slightly abraded as they are carried downstream. Differential movement in a flow takes place principally at its edges, where a reddish breccia and grooved and slickensided surfaces form. Like a glacier, a lava flow develops transverse crescentic ridges and lateral moraines. At its front movement is normally effected by the rolling forward of molten lava within, which carries down cooled blocks from the surface and piles them up ahead of the flow. As a flow dies the lava level lowers in the channel, and small side tongues break through the moraines. Some Parícutin lavas move considerable distances beneath older lava. The longest flow, which covered the town of San Juan in 1944, has a surface of rough curved slabs very different from the blocky surface of other flows but similar to the surface structures developed near lava orifices and by movement of viscous lava through fissures.

The complexities of this small lava field, produced simply by the movement of successive flows, would be difficult to interpret if found in older rocks.

INTRODUCTION

PURPOSE OF PAPER AND ACKNOWLEDGMENTS

The lavas of Parícutin Volcano, Mexico, offer an exceptional opportunity for studying the behavior of individual flows and the development of a small lava field. Many of the flows are fairly accessible at all points from their sources to their lower ends, and the history of each flow can be studied from its beginning to the cessation of lava movement. This report is based on observations made during the winter of 1945-1946, when conditions were particularly favorable as there was little falling ash to obscure surface details. Attention was concentrated on the moving lava, but the earlier ash-covered flows were studied briefly for purposes of comparison. The conclusions of this paper apply only to lavas now accessible to observation; according to W. F. Foshag (personal communication), some of the conclusions are not valid for earlier flows.

Most of the observations and conclusions presented in this paper are original only in the sense that they were made by me with little previous knowledge of the work of others. During and after my stay at the volcano I found that my observations were similar to those of many other geologist visitors. But nowhere, so far as I know, is there set down a complete series of observations focused on details of lava movement. The purpose of this report is to supply such a record.

Field work was undertaken by the U. S. Geological Survey in co-operation with the Instituto de Geología de México, the U. S. Committee for the Study of Parícutin, and the U. S. Department of State. (This is one of the scientific and cultural projects undertaken abroad under the auspices of the Interdepartmental Committee on Scientific and Cultural Cooperation, Department of State.) Facilities made available by

a grant from The Geological Society of America are gratefully acknowledged. In preparing this report the writer benefited greatly by discussions with other geologists familiar with the volcano, especially E. Ordóñez, Carl Fries, Jr., L. García Gutiérrez,

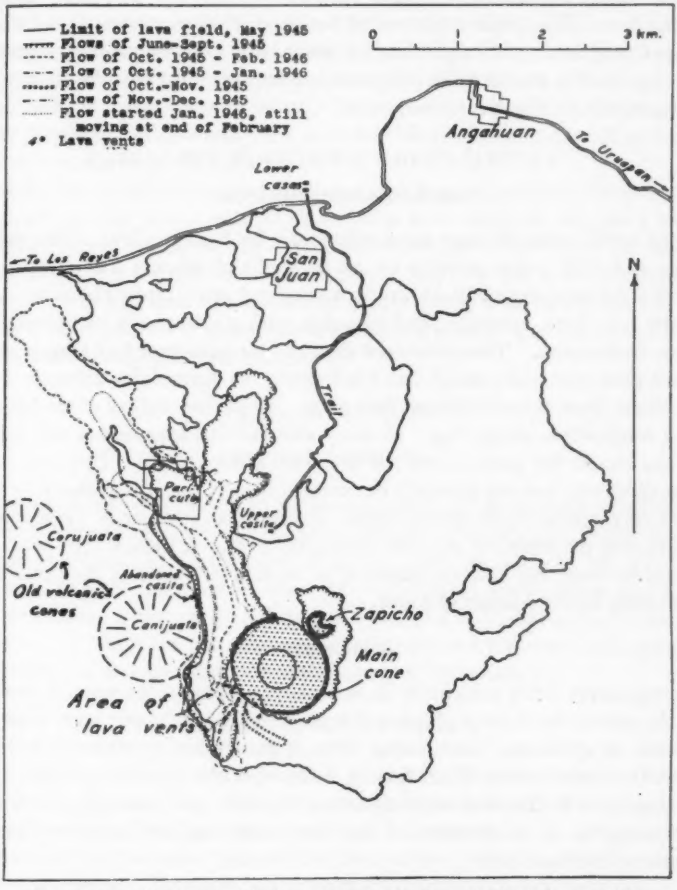

FIGURE 1.—*Sketch map of the lavas of Parícutin, June 1945 to February 1946*

and R. Molina Berbeyer[1]. To Antonio and Celedonio Gutiérrez the writer is indebted for assistance in the field and for much information about older lavas at Parícutin.

GEOGRAPHY

The distribution of flows during the winter of 1945–1946 is summarized in Figure 1.

[1] The most complete account of lava movement during the early history of Parícutin is given in a paper by E. Ordóñez (1945).

All the flows came from vents near the southwest base of the main cone of the volcano, and all the longer flows moved downslope to the north and west. The slope is mostly underlain by earlier Parícutin lavas, but the tips of the longer flows moved out northwest of the site of Parícutin village onto ground not previously covered by Parícutin lava. The gradient of most of the slope is low—between 4° and 8° on the upper part and between 1° and 4° on the lower part. In two places the gradient is steeper (up to 28°), one near the vents and one between the "abandoned casita" and the "upper casita" (Fig. 1).

GENERAL CHARACTERISTICS OF THE LAVA

PETROGRAPHIC CHARACTER

Olivine basalt seems the most appropriate term for Parícutin lava, although Milton (1945, p. 618–621) prefers andesite on the basis of high silica in a chemical analysis. The rock is monotonously uniform in appearance and petrographic character. Megascopically it is black, aphanitic, and vesicular, with scattered olivine phenocrysts up to 3 mm. in diameter. The microscope shows a groundmass of tiny plagioclase laths in brown glass containing much fine black dust. In some slides, feldspar is scarce, but in others there is more feldspar than glass. Refractive indices of the feldspar indicate a composition about An_{55}. In many slides olivine appears not only as phenocrysts but also as tiny grains about the size of the feldspar laths. Pyroxene is absent in most slides and was not certainly determined in any, but it is probably present in some as tiny grains in the groundmass. Except that feldspar is commonly more abundant near the lower end of a flow than near the source, there is little petrographic difference between one flow and another, or in different parts of the same flow, or between early and late stages of a flow.

STRUCTURES

Lava specimens differ principally in vesicularity. Specimens without vesicles are rare. In general the interior of a flow is least vesicular, the upper layer most vesicular. Lava in ephemeral, fast-moving flows is mostly highly vesicular and glassy, while that extruded slowly along fissures is less vesicular than the average. Directional structures in the lava are uncommon, but some specimens show banding and vesicles elongated in the direction of flow, and some thin sections show pronounced orientation of feldspar laths.

THE LAVA VENTS

Lava has come to the surface at various points over an area about 700 by 300 meters on the southwest side of Parícutin Volcano. During the winter of 1945–1946 the active vents were located along two fissure zones in this area, several tens of meters away from the base of the cone (Pl. 1, fig. 1). The zones comprised groups of branching cracks through the older lava, made conspicuous by the continual emission of bluish vapor and by deposits of white, pink, and yellow sublimate along them. The vents themselves were small sections of the fissure zones, changing their positions from time to time. A given vent might remain in the same position for several weeks, or

it might migrate along the fissure zone, or cease emitting lava and be supplanted by another vent elsewhere.

Although fluid lava is emitted at only one or two points along a fissure zone, the entire zone is obviously underlain by hot rock a short distance below the surface. Incandescent lava is visible in cracks and occasionally rises to the surface in small viscous extrusions. Fissures along the zone expand and contract as the lava beneath rises and falls; at times areas of several square meters along them collapse. Hos lava may remain in evidence below the surface for days or weeks after all active flowt have ceased moving from the fissure zone.

The actual size of the orifice from which the lava emerges is difficult to judge. The lava appears to come from a hole only a meter or so in diameter, but, since the flow commonly moves at first along the fissure zone or one of its branches, the lava may actually well up over a length of several meters. The fact that a flow widens from 1 or 2 meters to 9 or 10 within a short distance of the orifice, without any marked eddying and without much loss in speed, indicates that the conduit near the surface is not a circular pipe but a fissure several meters long.

LAVA MOVEMENT

KINDS OF MOVEMENT

Three kinds of lava movement can be distinguished: (1) the slow rise of viscous lava from fissures forming elongate domes and and thick curved sheets; (2) the rapid but short-lived movement of small flows of spongy lava in the area of lava vents, individual flows extending no more than 200 meters from their sources and moving for not longer than 2 days; and (3) long and persistent flows, extending at least half a kilometer from their sources and continuing to move for a week or longer. The third type is the most important in the building up of the lava field.

MOVEMENT OF LAVA AT THE VENT

Emergence of lava from a vent is generally quiet except for an occasional hiss or puff of trapped gas. The liquid material as it reaches the surface appears to be expanding slowly because of gas bubbles forming within it. Occasionally the amount of gas is larger and big bubbles collect beneath the lava surface; as each bubble expands the liquid is domed up, and the dome finally breaks and spatters bits of fluid lava outside the vent. The formation and breaking of a bubble may take anywhere from a fraction of a second to several seconds; if the time is short the noise is like the puffing of a steam engine. Rarely, the emission of gas is so rapid that the lava in the vent boils almost continuously, spouting large irregular masses of liquid several meters into the air. The action at a vent may change from quiet emission to active spouting, or the reverse, within a few minutes.

The projection of fluid fragments from a vent and several small overflows of lava in directions different from that of the main flow may build up a steep-walled amphitheatre around the lava orifice. Depending on their history, some vents have amphitheatres 5 or 6 meters high, while others are practically without walls.

MOVEMENT OF LAVA IN A LONG FLOW

Velocity of lava movement.—The speed of lava movement in a long flow depends on slope, width of flow, and distance from the source. Doubtless it depends also on thickness, shape of channel, temperature, and gas content, but the influence of these factors is less obvious. The fastest movement recorded was 60 meters per minute, in the middle of a flow on a 28-degree slope only a few tens of meters from the source; this is close to the maximum reported by Ordóñez (personal communication) for earlier Parícutin lavas—75 meters per minute. More commonly rates are between 20 and 40 meters per minute on steep slopes and between 1 and 10 meters per minute on gradual slopes. The lower end of one of the flows, at a distance of 4 kilometers from its source, advanced nearly a kilometer in 7 days, but generally the rate of advance is much slower.

Dimensions of a long flow.—A moving flow near its source is commonly from a few meters to 20 meters wide; far from the source the usual width of a well-defined flow is of the magnitude of 100 meters. When a flow moves from a gentle slope onto a steep slope it generally splits into two or more narrow branches (each 3 to 20 meters wide) which spread out and reunite at the base of the steep slope. Thicknesses of flows near their lower ends range from 2 to 9 meters but are commonly between 5 and 7 meters.

Calculation of the amount of lava moving in a flow is possible when the lower end of a flow maintains a fairly definite width and rate of movement for several days. Such calculations indicate that lava is supplied to one of the major flows at a rate of between 100,000 and 300,000 cubic meters per day, and that within the period from October to March the total amount of lava emitted per day was seldom less than 200,000 or more than 500,000 cubic meters.

Temperature of the lava.—Temperatures of the moving lava were measured with both an optical pyrometer and a thermocouple. The highest temperature obtained, close to one of the vents, was 1070°C.; previous workers have recorded temperatures as high as 1100°C. (Zies, 1946). Temperatures downstream are only a little lower; even at the ends of flows 4 or 5 kilometers from their sources temperatures of 1000° to 1050°C. were recorded. The maintenance of temperature for such a distance is due partly to insulation by the cooled lava on top of a moving flow and partly probably to heat given off by the lava as it crystallizes.

Viscosity of the lava.—Viscosity may be calculated from the Jeffreys formula (cited by Nichols, 1939)

$$u = \frac{g \sin A \, d^2 p}{3V}$$

in which g is acceleration of gravity, A is slope, d is depth of the flow, p is density, and V is mean velocity with respect to depth. The faster Parícutin flows, near their vents, have maximum surface velocities between 20 and 40 meters per minute on slopes of 15° to 25°; the mean speeds can be taken as about half of these figures. Depths cannot be directly measured but can be estimated (1) by observing the depth to which the lava level lowers in the channel when a flow dies, and (2) by determining the rate of advance of the foot of the flow where the depth is measurable

and assuming that the quantity of lava moving in all parts of the flow is the same. These methods indicate that depths in the upper parts of flows are seldom less than 1.5 meters or greater than 4 meters. The density of moving lava also is not determinable directly but probably lies between 1.5 and 2.5 grams per cubic centimeter. Viscosities calculated from these figures lie between 10^5 and 10^6 poises.

The validity of such calculations has been critically examined by Wentworth, Carson, and Finch (1945), who point out the uncertainties in the measurements, the extrapolation involved in applying Jeffreys' formula, the neglected retarding effects of drag by the sides of the channel and the cooled blocks on the upper surface, and the probable variation of viscosity from point to point within the flow. They indicate that the value given by Nichols (1939) for a Hawaiian flow, 4.3×10^4 poises, has meaning only as an order of magnitude. It seems worthy of note that values obtained for Parícutin lavas are at least one order of magnitude higher than that indicated by Nichols. The higher viscosity is probably related to the lower temperature of the Parícutin flows: 1050° to 1070°C., opposed to an estimated 1150° to 1200°C. for the Hawaiian flow.

The viscosity of the lava patently increases downstream. The very high viscosity at the lower end of a long flow is strikingly shown by the behavior of blocks of incandescent lava that break away from the moving front. When one of these blocks rolls down slowly it is indented by the cool blocks in its path and as it comes to rest adjusts its shape somewhat to its surroundings; but if it falls freely even a short distance, so that it strikes another block sharply, the incandescent material shatters like a brittle solid.

In general, lava of the small, short-lived flows appears to be less viscous than that in the principal flows, while lava in the domelike extrusions along fissures is more viscous.

History of a flow.—The actual birth of a major flow was observed only once by the writer during this study. In this case viscous lava simply welled up slowly from a fissure; at the time it seemed like one of the minor extrusions common in the area of lava vents, but by the following day a steady stream of less viscous lava was in motion. Evidently the birth of a flow is sometimes more spectacular, a new vent spouting lava fragments and much gas for a day or two before settling down to quiet emission.

In the early stages of a flow several tongues may overflow from the new vent, but eventually most or all of the movement becomes concentrated into a single channel. Once the channel is established it normally changes little during the life of a flow. There may be some migration from side to side; a sudden increase or decrease in the supply of lava from the vent may cause a change in course; a flow is sometimes deflected by an unusual accumulation of surface debris; but in general channels are remarkably persistent. Within its channel the level of a flow commonly fluctuates through a vertical range of 1 or 2 meters.

The most curious change in the channels is their gradual building up to a considerable height above the surroundings, much as a river channel confined by levees is built up as the stream drops sediment in its bed[1]. The mechanism of the building-

[1] A similar raised channel of a Vesuvian flow is described by Perret (1924).

up process is unknown; perhaps there is sufficient heat loss at the base of a flow to cool the bottom layer very slowly, or perhaps motion of the fluid carries small cooled blocks and degassed lava from the top to the bottom of the flow. Whatever the cause, two of the major flows in a period of several weeks built up their channels

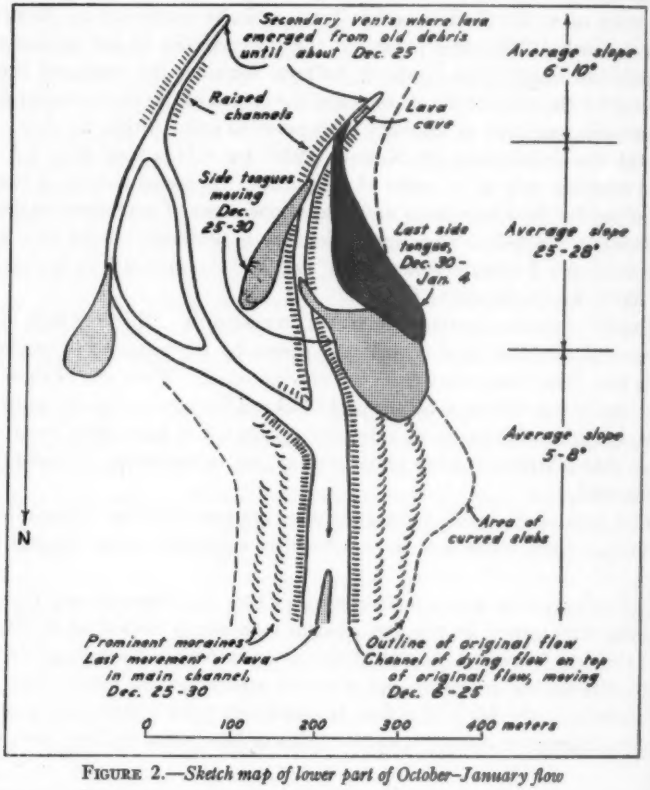
Secondary vents where lava emerged from old debris until about Dec. 25
Average slope 6-10°
Raised channels
Lava cave
Side tongues moving Dec. 25-30
Last side tongue, Dec. 30-Jan. 4
Average slope 25-28°
Average slope 5-8°
N
Area of curved slabs
Prominent moraines Last movement of lava in main channel, Dec. 25-30
Outline of original flow Channel of dying flow on top of original flow, moving Dec. 6-25
0 100 200 300 400 meters

FIGURE 2.—*Sketch map of lower part of October–January flow*

locally to a height of at least 15 meters above the original level. Even in these high channels the flows are persistent; small tongues may break over the edge, and lava may ooze out at the base of the levees, but the main flow usually remains in the channel.

When the lava supplied from the vent begins to diminish in amount, the first response of a flow is for its level to lower in the channel. The lowering usually is only 1 or 2 meters but locally may be as much as 6 meters. The vent appears to migrate slowly downstream, leaving behind it a row of curved slabs convex upstream to mark its various positions; this migration, incidentally, is further evidence that the lava orifice is actually a considerable length of fissure rather than a narrow tube. The next and surest sign of cessation of a flow is the appearance of small lava tongues

either spilling over the side of the channel, moving on top of the surface debris within the channel, or burrowing under the debris in the channel (Fig. 6). Evidently when the supply of lava begins to fail parts of the flow freeze and dam the still-moving lava behind them, forcing it either to rise up on top or to spill over the side.

In a big flow some movement of lava persists for a long time after the supply of lava has stopped. For example, in a flow with a total length of 3 kilometers, the supply of lava from the vent began to diminish in late November and practically ceased by December 9; motion at the lower tip of the flow stopped before December 7, but small lava tongues in various parts of the flow continued to move until January 4 (Fig. 2).

Small lava caves are sometimes produced in the declining stages of a flow, when molten material drains from under a particularly thick portion. Most of such caves at Parícutin have only a brief existence; their walls collapse within a few days or weeks.

When a new flow moves into the channel of an older one the two flows will join if the earlier one is moving. But if the source of supply has been cut off from the earlier flow for as much as a day or two, the new flow simply rides over the top of the other or breaks across its channel. Rigidity sets in very soon when a lava flow dies, even though small parts may show fluidity for weeks afterward.

Details of motion in a flow.—As lava emerges from a vent it is undergoing vesiculation by the expansion of dissolved gas. The surface cools into a black, spongy crust which hardens and is broken into chunks by the continued movement beneath. These cooled blocks, ranging from a few centimeters to a meter or so in diameter, are pulled apart, rotated, and broken, while more of the molten vesicular lava comes to the surface between them. Within a few meters of the vent so much surface crust has formed that incandescent lava appears only in cracks between the jagged vesicular blocks.

Even close to the vent the flow becomes a well-defined stream with zones along each edge 1 to 2 meters wide in which most of the differential movement takes place. Within these zones the cooled surface blocks are rotated horizontally, ground against one another and against the stationary rocks at the side, and gradually rounded and fragmented. Out in the middle of the flow differential movement is much less evident; blocks for the most part simply float downstream and only occasionally shift position. The movement is sufficient, however, so that the blocks are gradually reduced in size and angularity.

The flow widens from the instant it leaves the vent. It may be constricted to a width of 6 or 7 meters as it traverses the steep slope near the vent, but below the slope it spreads out to 30 meters or more. In this wider channel most of the differential movement still takes place within 1 or 2 meters at the edge of the flow. In the moving part of a simple flow, motion is somewhat faster in the middle than on either side; but flows are so often complicated by branching, by the addition of tributaries, and by irregularities in their beds that the motion in many places appears to follow no simple rule. It is not unusual to find rapid motion in a narrow channel near one edge, while the center of the flow remains sluggish. To casual observation

individual surface blocks appear simply to float with the current, but more extended watching shows that the blocks do actually shift position slowly. Their movement is also indicated by the sound of a moving flow—a medley of metallic clinks, which at a distance blend into a continuous rustle like that of moving water.

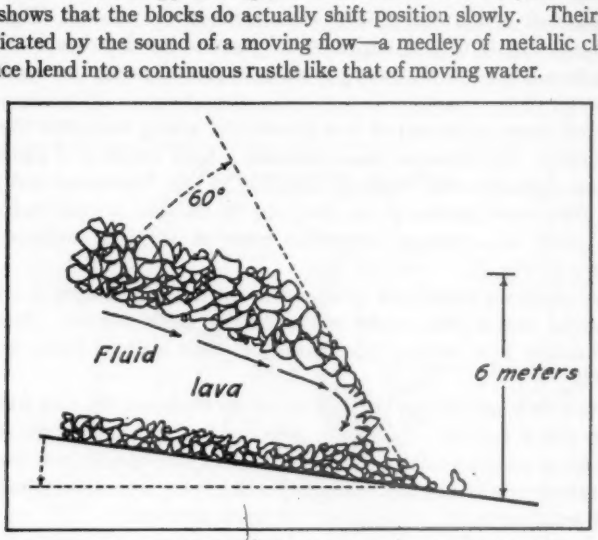

FIGURE 3.—*Longitudinal section through moving tip of typical flow*

The evolution of gas, at first general from the surface of a flow, becomes more and more concentrated in the zone of differential movement at either edge. The gas produces a slight alteration in the lava, turning its original jet-black color into gray or reddish black. Hence from a distance a moving flow appears as a long black tongue flanked by strips of gray.

For most of its length a flow maintains a definite channel, but near its lower end it commonly spreads out into broad lobes. As the front moves forward the channel extends itself across the lobate area. Thus a mature flow normally consists of a channel of moving lava roughly 100 meters wide flanked by belts of cold lava, the channel losing its form a few hundred meters back from the moving tip. (The light-gray flow in middle of photo, Pl. 1, fig. 2, is a good example.)

When a flow moves from a gentle slope onto a steep slope, it commonly divides into two or more narrow branches. These branches spread out and thicken at the base of the slope, piling up a lava fan much as a stream piles up an alluvial fan. Within a short distance the branches coalesce to form a flow of normal width.

The lower tip of a moving flow is a pile of loose blocks, generally 5 to 7 meters high. If the movement is slow there may be no incandescent material visible, and movement is shown only by the occasional dropping of blocks down the front and by the noise of blocks scraping against one another. A front of this sort commonly maintains an angle of about 40°. Where the motion is more rapid, fluid lava appears in a rounded bulge at the front, about a third of the way up from the base of the flow (Fig. 3), and an angle of about 60° is maintained. The molten rock moves by a forward-rolling motion, as would any highly viscous material; this motion carries

cool blocks from above forward until they spill over the front and fall at the base. Added to these blocks are fragments formed by the cracking and breaking off of chunks of the incandescent material itself. Thus the lava moves over a floor of cooled blocks which it continually lays down ahead of itself. This mechanism,

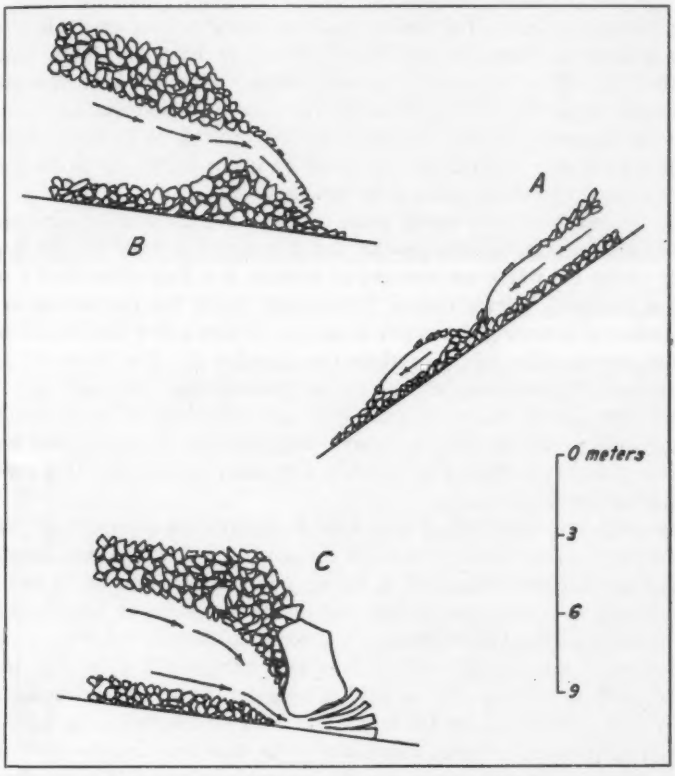

FIGURE 4.—*Longitudinal sections through ends of three flows*
Showing variations from the normal form

similar to that of a caterpillar tractor, is a very efficient one for movement over rough terrain. This kind of motion is described also by Sapper (1927).

Other types of movement at the lava front are shown in Figure 4. Where the slope is very steep (greater than 30°) (Fig. 4A) the flow becomes thin (1 to 2 meters) and moves in part by sliding rather than rolling; narrow tongues are formed, from which portions break off and slide bodily downhill. At times debris piles up higher than usual ahead of the flow (Fig. 4B); the molten rock ultimately surmounts it and moves downward over it as a thin, fast-moving tongue. In various ways lava from the lower part of a flow may be forced to the surface through a narrow crack (Fig. 4C). This lava behaves as if somewhat more viscous than the flow as a whole.

As it oozes slowly out of the crack it hardens but does not immediately break up, so that presently it forms a curved slab several centimeters thick with roughly corrugated surfaces. Small areas of these curved slabs, generally less vesicular and less altered than the more common blocks, are frequently encountered along the lava fronts.

Surface details of flows.—The surfaces of most Parícutin flows are made up chiefly of loose subangular blocks between 10 and 100 cm. in diameter. These blocks are evidently produced by the breaking up and abrasion of the crusts formed when the lava surface is exposed to air. Some of the blocks are black and unaltered, but many have surface layers turned gray or reddish black by gases from the hot lava beneath. Individual flows may often be distinguished by minor differences in average size, vesicularity, or degree of alteration of the surface blocks.

Parts of some flows have nearly plane surfaces, but much more commonly the surface blocks are heaped into mounds and ridges with a relief of 1 to 3 meters. In many places the ridges are arranged at random, but they often show a striking pattern of crescentic curves convex downstream, much like the pattern of ridges on the surface of a moving glacier (Pl. 1, fig. 2). Where a flow has heaped up large piles of its own or older debris, or where two branches of a flow have split and left a gully between, the relief may be much greater than the usual 1 to 3 meters.

A prominent surface feature of some flows is reddish breccia in piles, walls, and sharp pinnacles, evidently material produced by abrasion of nearly solid lava and altered by gases. The breccia is especially common near the edge of a flow where differential motion is greatest.

A less common surface feature is an area of curved slabs of fresh lava, evidently formed where viscous material wells up through a crack. The most common of these areas are elongate domes (Pl. 2, fig. 1), 2 to 3 meters wide and 1 to 2 meters high, generally split down the middle and divided transversely into curved slabs convex upstream. Sometimes the lava has come up through the crack as a single thin sheet, curving to one side or both sides as it emerged (Pl. 2, fig. 2). In places curved slabs lie at random over an area of irregular shape. The slabs are mostly 10 to 30 cm. thick but in places are very thin. Flow structures such as banding and drawing out of vesicles are much commoner in the slabs than in other kinds of lava.

Details of motion at the margin of a flow.—Lava movement is strikingly similar to glacier movement. Like a glacier, a flow carries debris on its top, drops the debris in front of its moving tip, and partly overrides it. Like a glacier a flow develops crescentic ridges on its surface which show the differential movement between center and edges. Also like a glacier a flow builds along its sides well-developed lateral moraines, consisting of loose blocks pushed aside as the flow moves.

Normally the top of a flow is 1 or 2 meters below the crest of its bordering moraines, but as its level fluctuates it often rises temporarily to their height. When a flow stands high in its channel the outward shove on the moraines causes them to move slowly, in much the same manner as the front of the flow itself; blocks fall from the top one by one, and locally small tongues of incandescent lava appear on the outer slopes of the moraines. Moraines may be found along any part of a flow that maintains a definite channel (Pl. 1, fig. 2, light-gray flow in middle part of picture).

FIGURE 1. AREA OF LAVA VENTS IN NOVEMBER 1945
As seen from side of cone. Two fissure zones shown by lines of vapor and light-colored sublimate. When this picture was taken one flow was moving from each fissure zone; the two vents are indicated by the arrows.

FIGURE 2. VERTICAL AIRPLANE PHOTOGRAPH OF LOWER ENDS OF TWO FLOWS THAT WERE MOVING IN SUMMER OF 1944
Light-gray flow in middle part of photograph shows typical structural details: lobate margin, well-defined channel to within a few hundred meters of the end, lateral moraines bordering channel, and transverse ridges across channel. Tongue in upper part of photograph is part of San Juan flow, showing abnormal structure without definite channel or moraines, its surface made up chiefly of thick curved slabs. (Photo by Compañía Mexicana Aerofoto, S. A., México, D. F.)

LAVA VENTS AND STRUCTURAL DETAILS OF PARÍCUTIN FLOWS

FIGURE 1. ELONGATED DOME OF CURVED SLABS
Formed by viscous lava rising along a crack.

FIGURE 2. THIN, STRIATED SHEETS FORMED AS LAVA RISES OUT OF INCLINED FISSURE

FIGURE 3. SURFACE OF SAN JUAN FLOW
Showing thick slab of massive lava with corrugated spongy surface.

In places several parallel moraines are visible, indicating different positions of the edge of the flow. Most of the blocks making up the moraines are somewhat altered from black to shades of gray and reddish black, because gas emission is strongest near the edge of a flow.

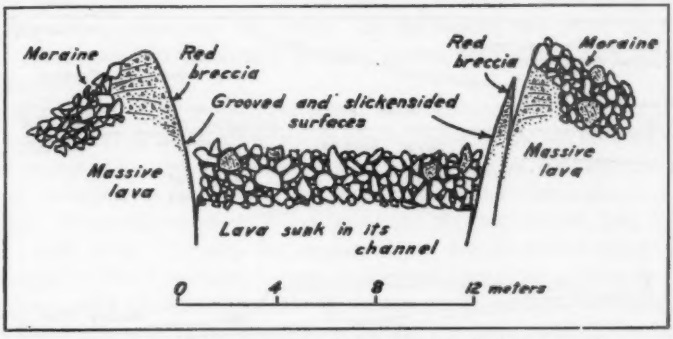

FIGURE 5.—*Transverse section through flow whose level has lowered*

Details of subsurface movement at the edge of a flow are most clearly shown where the level of the lava has lowered in its channel. The channel sides below the moraines are nearly vertical walls, with fluting, slickensides, striae, and chattermarks of the same sort that a glacier leaves when it moves against a vertical surface (Fig. 5). The grooves and striae are approximately parallel to the direction of lava movement. The walls are made up in part of massive lava, in part of breccia, but are coated with a fairly hard reddish material evidently consisting of rock powder formed by movement along the surface and partly welded by the heat of the lava. The presence of these steep walls suggests that subsurface differential movement at the edge of a flow is largely localized at a single surface separating nearly solid lava from the moving flow. In many places, however, two or three parallel walls are visible, and "gash fractures" cut into the walls at small angles downstream, indicating that movement takes place through a narrow zone rather than on a single surface.

The red breccia abundantly developed along the margins of flows and locally elsewhere is a soft rock consisting of lava fragments, mostly small and angular, in a matrix of red powder. The fragments themselves include all varieties of basalt, from nearly massive to spongy and from black to reddish black and friable; the great majority of them show some alteration. The breccia is evidently produced by movement in hot but nearly solid basalt, and partly altered by gases during and after its formation. The development of the breccia can often be observed at the lower end of a flow, where blocks of incandescent but solid basalt are fractured and ground to powder as they move against one another. An accumulation of incandescent sand and dust produced by the grinding is visible here and there in crevices in the lava. Fallen blocks at the front of a moving flow show all stages in the formation of breccia, from cracked and slightly reddened lava to soft red powder. Some of the fine reddish material is hard, and boundaries of fragments in it are indistinct, suggesting that it has been welded by the heat of the lava.

The breccia at the edge of a flow is surmounted by and partly mixed with the moraine at the surface; blocks of breccia are common in the moraines. Downward the breccia grades into the massive or nearly massive basalt which makes up the interior of the flow.

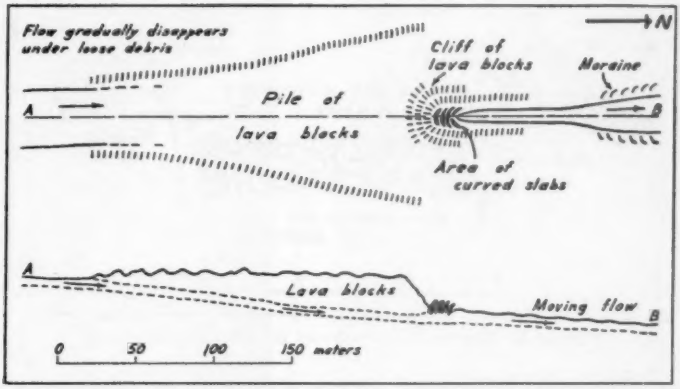

FIGURE 6.—*Sketch map and section of flow moving under debris of older lava*

Locally outside the moraine at the edge of a flow there is developed an area of fresh gray to black lava in thick curved slabs, the same sort of lava found in elongate domes along fissures. Some of these patches are obviously formed by lava from the lower part of the flow leaking out under the moraine through small cracks. Probably all these areas are formed in a similar manner, but some are so large (up to 100 by 400 meters in area) that details of the process are not clear. The largest areas appear at turns in lava streams, where pressure on the walls of the channel is abnormally high.

Movement under earlier Parícutin lava.—A frequently observed characteristic of the Parícutin flows is their ability to disappear under earlier Parícutin lava and then emerge several hundred meters downstream, elevating the earlier lavas in the process. Lava has clearly moved completely under earlier flows, prior to the winter of 1945–1946, but during this period underground movement was probably confined to flow beneath accumulations of surface debris. It became conspicuous only where these accumulations were unusually thick, particularly on the gently sloping area between the northwest base of the cone and the old cone called Canijuata (Fig. 1).

Typically the vanishing of a lava stream beneath surface debris involves simply the gradual disappearance of a distinct channel and the gradual fading out of perceptible motion as the flow is followed along the surface. In other places the entire flow does not vanish, but the appearance of a subsidiary stream emerging from old debris near the main stream suggests that some of the lava is finding its way underground.

Lava emerges from its subsurface channel through a vent much like one of the original vents, commonly at the base of a steep slope of loose blocks (Fig. 6). It

moves more slowly, of course, than lava at a primary vent, has almost no visible vapor rising from it, and is covered over by frozen blocks within a few meters of the orifice. Commonly it appears to move upward as well as outward, as if under considerable hydrostatic pressure from lava above and behind it. This upward and outward motion, similar to that which produces elongate domes along a fissure, forms big curved slabs near the orifice. In the moving flow itself the slabs are turned and abraded so that a few hundred meters downstream they become the normal subangular blocks.

A curious type of subsurface movement is sometimes observable at the steep margin of the lava field when a new flow moves on top of the old lava within a few tens of meters of its edge. The steep outer slope of the old lava appears to bulge outward, incandescent lava appears in deep cracks, and blocks begin to roll down the slope. The total movement is not large, and the incandescent lava disappears within a week or so. Probably the pressure of new lava above has simply caused a readjustment in the older material, pushing sideward some of the still-hot and slightly plastic lava which remains under the apparently cooled surface. Perhaps there is some transfer of heat from the new lava to the old, but there could hardly be enough to produce incandescence if the old lava had cooled completely.

The San Juan flow.—A puzzling question about the Parícutin lavas is the reason for the unique characteristics of the long flow that engulfed San Juan Parangaricutiro in the summer of 1944. While all other observed flows from the volcano have the typical blocky surface described above, the entire lower half of the San Juan flow is made up of the thick curved slabs that elsewhere occur only in small areas near lava vents, along fissures, and at the edges of flows. Moreover, the lower half of the San Juan flow lacks the definite channel and the moraines so characteristic of other flows (Pl. 1, fig. 2). Locally, movement of the flow is said to have been unusually rapid[3]. Lava alteration is inconspicuous, and remains of old fumaroles are practically absent, suggesting less gas emission than usual during and after lava movement. The flow has a greater total length (about 10 km.) than any other Parícutin flow. Despite all these differences, the San Juan lava both in hand specimen and under the microscope seems identical with fresh specimens from other flows.

The photograph of the surface of the San Juan flow (Pl. 2, fig. 3) shows one of the typical thick slabs, here 50 or 60 cms. thick, massive or slightly vesicular for the most part but with a corrugated surface of spongy material. In many places the slabs are somewhat thinner and are curved into fantastic shapes. Often the slabs stand on end, with chasms several meters deep between, so that the flow is almost impossible to cross on foot. The surface is best classified as a variety of aa.

The fact that the slabs persisted as such indicates that the motion in this flow must have been different from the usual jostling of blocks floating on moving lava. The type of motion can perhaps be inferred from the behavior of lava during the formation of elongate domes along fissures: Lava is pushed up slowly from beneath, splitting into slabs as it cools and contracts; then each slab grows as it is pushed outward, plastic at its base but cold and hard in its upper part. Further evidence regarding the mechanism of flow is obtained from a cross section through a small

[3] Ordóñez (1945) reports 250 meters in 24 hours for the main stream west of San Juan.

tongue of this kind of lava cut by a stream (Fig. 7). The curved slabs apparently grow upward out of the massive interior and bend forward as they are pushed up. This same type of movement is observed near the vents of other flows, especially at secondary vents where flows emerge from under old debris; the chief difference is that near the vents the slabs are thin and vesicular and break up readily as they are carried downstream.

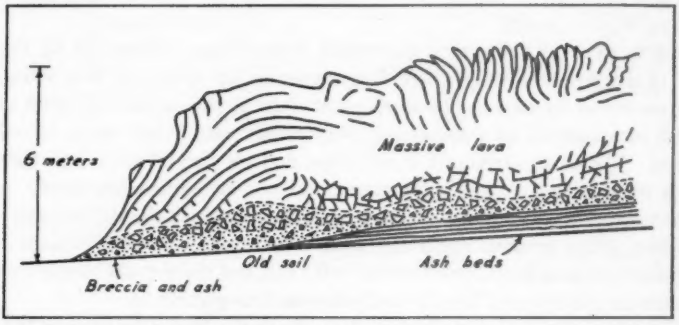

FIGURE 7.—*Longitudinal section through tip of small tongue of "San Juan type" lava*

The essential characteristic of the San Juan flow, therefore, is the formation in its lower portion of curved slabs thick enough and strong enough to persist as slabs instead of breaking up into blocks. What this means about the physical state of the lava can only be guessed. Where small tongues from other flows develop the "San Juan type" structure, the lava appears to have a normal temperature, an abnormally high viscosity, and an abnormally low gas content. In the one place where blocky and "San Juan type" lava were observed forming on the same lava front within a few meters of each other, the "San Juan type" seemed to be coming from a lower level in the flow—where perhaps high viscosity and low gas content would be expected. Although lava in these small tongues closely resembles San Juan lava, its high viscosity and slow motion do not fit the reported fairly rapid movement of the San Juan flow. Possibly the peculiarities of the San Juan lava can be accounted for by a low gas content, permitting the formation of thick slabs, combined with a high enough temperature to make the lava more fluid than that in the small tongues. Unfortunately there are no recorded temperature measurements on the San Juan flow to check this guess.

APPLICATION TO OLDER LAVAS

Observations of the growth and development of individual flows at Parícutin show clearly how complex a lava field can become even when only one petrographic type of lava is present and when the building up of the field is disturbed by nothing except occasional falls of fine ash from the crater. If this field were to be buried and partly exhumed in a later geologic era, it would be difficult to trace the boundaries between one flow and the next, since different tongues of the same flow would overlap one another and since some flows would have moved under older ones.

Massive lava and several different types of breccia would be complexly interlayered. Doubtless some of the breccias mixed with ash would resemble pyroclastic breccias, while others would have all the characteristics of fault breccias, including association with grooved and slickensided surfaces. Flows that moved under older flows would show apparent intrusive relations. Yet all this complex structure has developed in the normal course of movement of successive lava flows.

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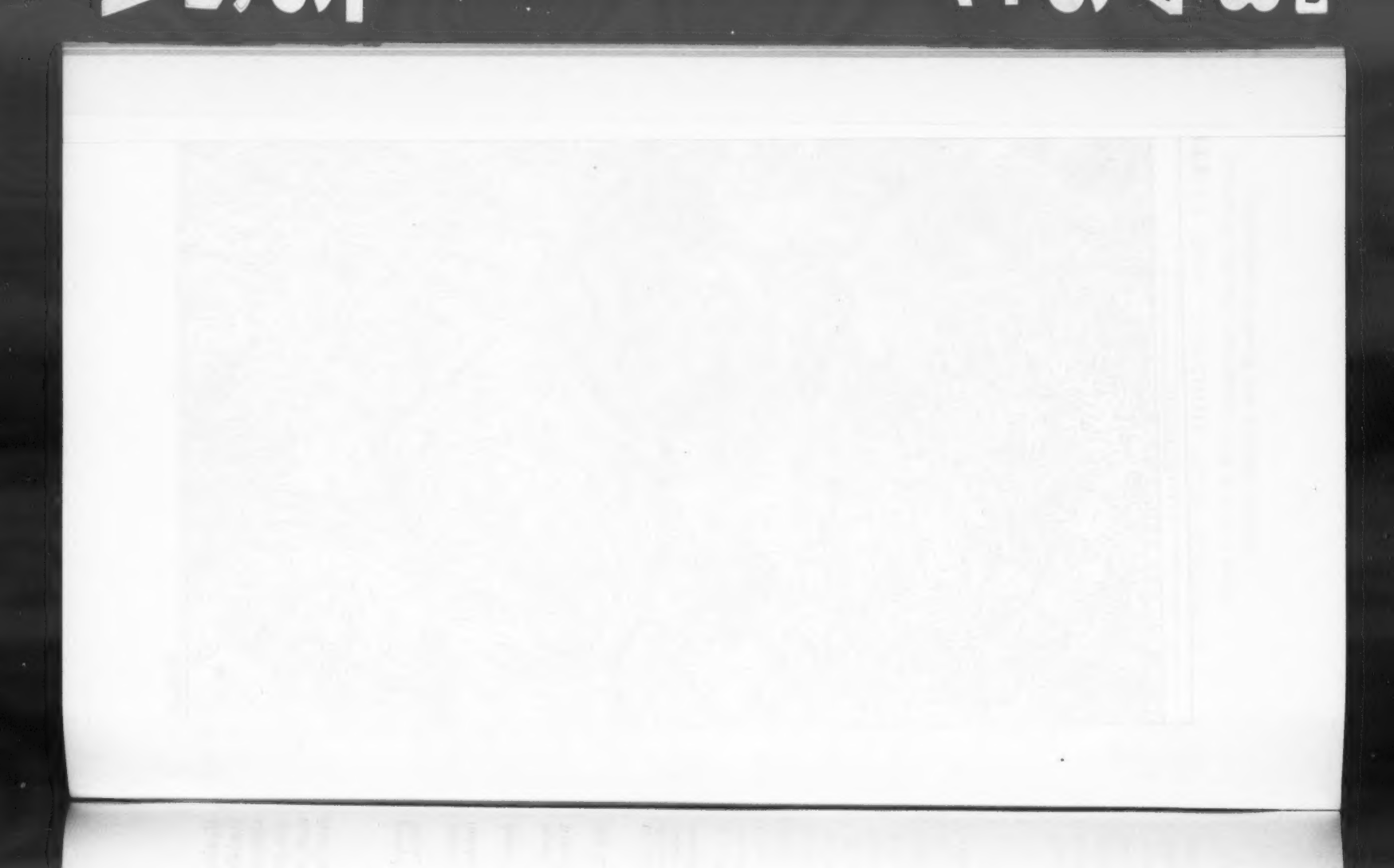

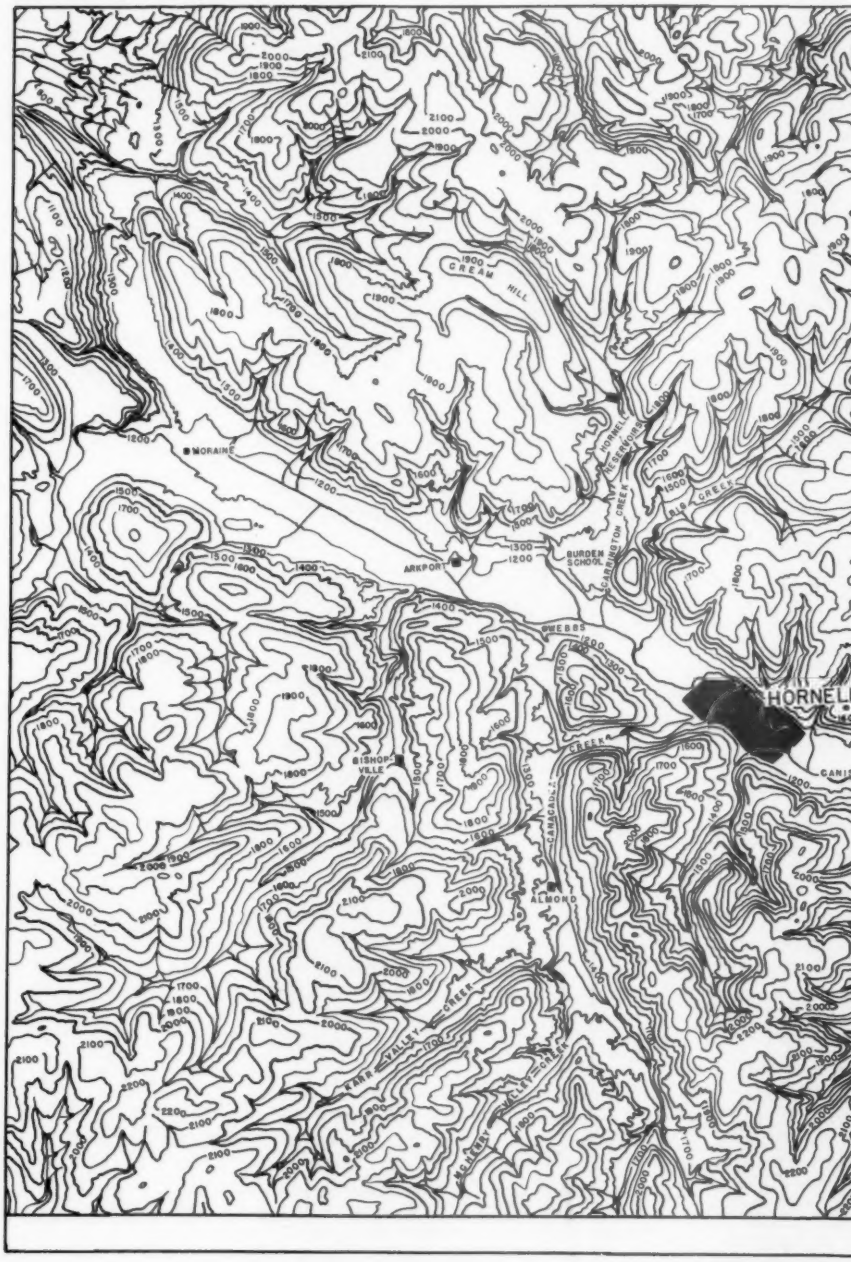

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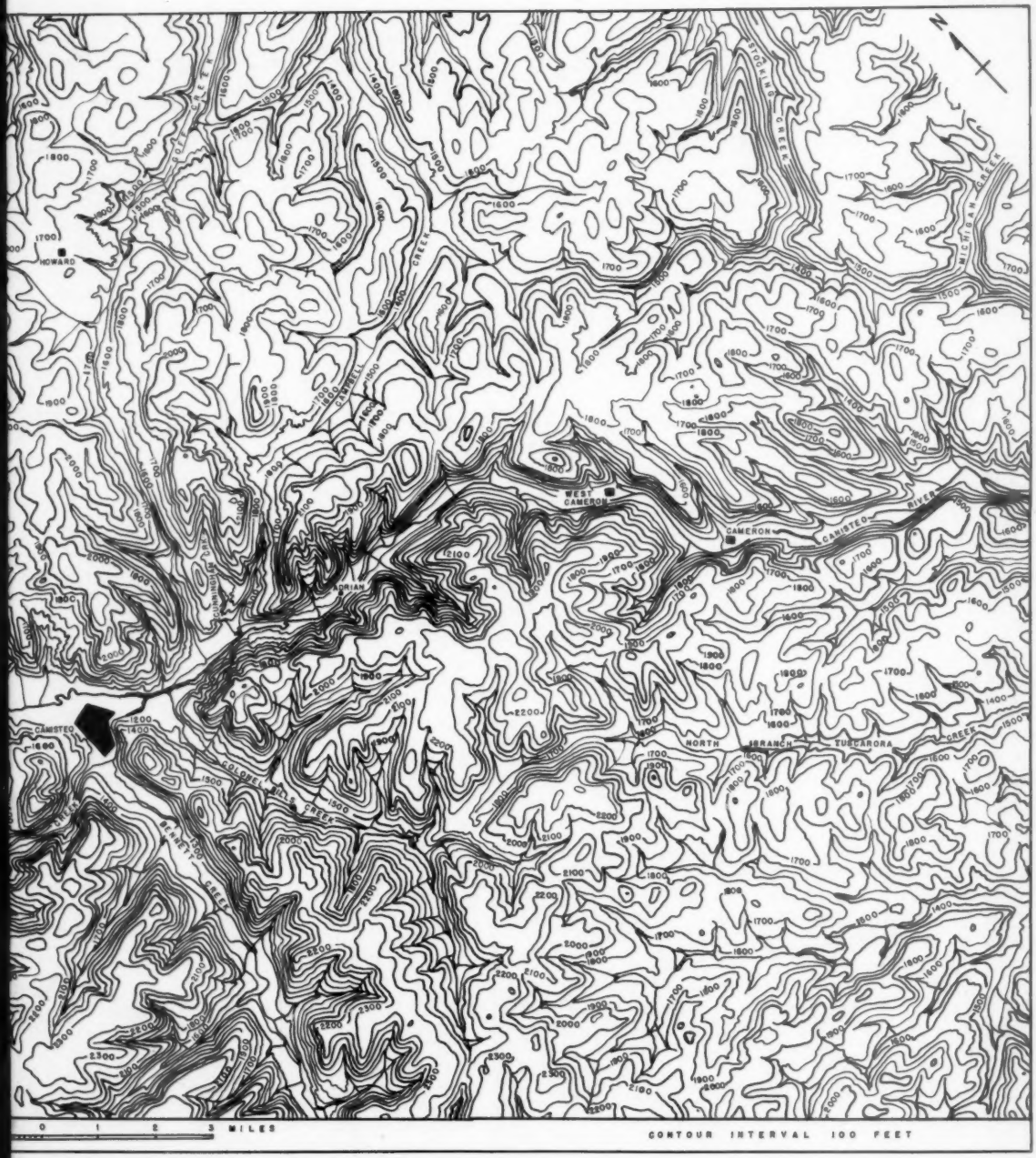

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GLACIAL STREAM DIVERSION NEAR HORNELL, NEW YORK

BY ALBERT E. WOOD

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ABSTRACT

The Almond Dam near Hornell, in south-central New York, is at the site of a glacial diversion of Canacadea Creek. Here the diversion valley is about 1200 feet wide, with rock about 75 feet below the creek level. The rock in the preglacial valley is considerably deeper, and the valley is about twice as wide. The diversion valley is filled with blue till, above which are water-lain deposits with an overlying

brown till. The Canacadea Valley thus indicates three advances of ice sheets, to form the diversion and to deposit the blue and brown tills in this valley. The valley of Purdy Creek shows similar conditions.

At eight other localities, local changes occurred at or near the close of the last glaciation. At the Arkport dam site, the preglacial valley has been blocked by glacial deposits, and the stream has cut a new, meandering channel in the rock wall south of the old valley. This new valley has been partly refilled with stream gravels. Farther upstream, near Bishopville, is a similar stream diversion. At the dam sites on Carrington Creek, Big Creek, and Karr and McHenry Valley creeks and on Cunningham and Hammer creeks the history appears to have been identical. These represent postglacial drainage changes.

INTRODUCTION

Studies were made, between 1936 and 1940, for the United States Army Engineers, of a number of potential sites for flood-control dams on headwater tributaries of the Canisteo River above Hornell, New York. Two sites on the Canisteo River west of Arkport and on Canacadea Creek east of Almond were selected for construction. The first dam was completed in 1939, and construction of the second began in 1947. Most of the information used in this article was derived from the explorations (particularly drilling and seismic explorations) made for the U. S. Engineer Department at and near the Arkport and Almond sites, but the results of work in connection with four other dam sites in the same area and independent explorations elsewhere are also incorporated. The field work on which this paper is based was performed while the author was Geologist for the Binghamton District, U. S. Engineer Department, and all the maps except Plate 1 and Figure 2 are based on surveys made by the Binghamton District.

The author wishes to express his appreciation to the former Binghamton District, U. S. Engineer Department, for permission to use the maps and drilling and seismic data, and to the Chief of Engineers, U. S. Army, for authorization to publish this paper.

Hornell is in south-central New York (Fig. 1), near the northern margin of the Allegheny Plateau, which here is a rolling upland 2100–2300 feet above sea level. The bedrock is alternating sandstones and shales dipping at low angles, usually to the southwest, although there are gentle swells, domes, and saddles (Bradley and Pepper, 1938). There are two major sets of joints, striking about N.30°W. and N.65°E. respectively and dipping between 70° and 90°. Many of the valleys parallel the strike of these joints and were probably initiated by them. One set of joints appears to have controlled the course of the broad valley partly occupied by the Canisteo River ("Hornell Valley") from Hornell to Moraine, of Colonel Bill's Creek, of parts of Bennett Creek, of parts of the Canisteo River downstream from Canisteo, and of many minor tributaries; while the other seems to have controlled the upper parts of Big Creek, Karr Valley Creek, McHenry Valley Creek, Purdy Creek, Campbell Creek, the Canisteo above Bishopville, and many minor tributaries (Fig. 2; Pl. 1). In preglacial times, the region reached a submature stage of dissection with greater relief than at present. Many of the streams now flow in straight, parallel-sided, flat-bottomed valleys. Probably the parallel trend of the valley walls and the absence

of transverse spurs has been accentuated by glacial erosion. The flatness of the valley bottoms is due to extensive glacial or postglacial sediments.

All potential flood-control dam sites are at localities where drainage has been modified by glacial activity. The diverted valleys fall into two categories: (1) those which

FIGURE 1.—*General location of Hornell, New York*

are about half the width of the preglacial valleys, with rock close to both walls, but containing extensive glacial deposits above the rock floor; and (2) those much narrower, containing no glacial deposits and with rock at or near the present stream level and exposed along both walls. Group (2) must have been caused by the last advance of the ice in this region, and (1) by an earlier advance. The large amount of subsurface information available for these sites warrants the presentation of the data in some detail.

DOUBLE-CYCLE DIVERSIONS

ALMOND DAM SITE

Canacadea Creek is the first main tributary of the Canisteo River from the southwest, entering the Hornell Valley at Hornell. For most of its length, Canacadea Creek flows generally northeast. Halfway between Almond and Hornell, the creek

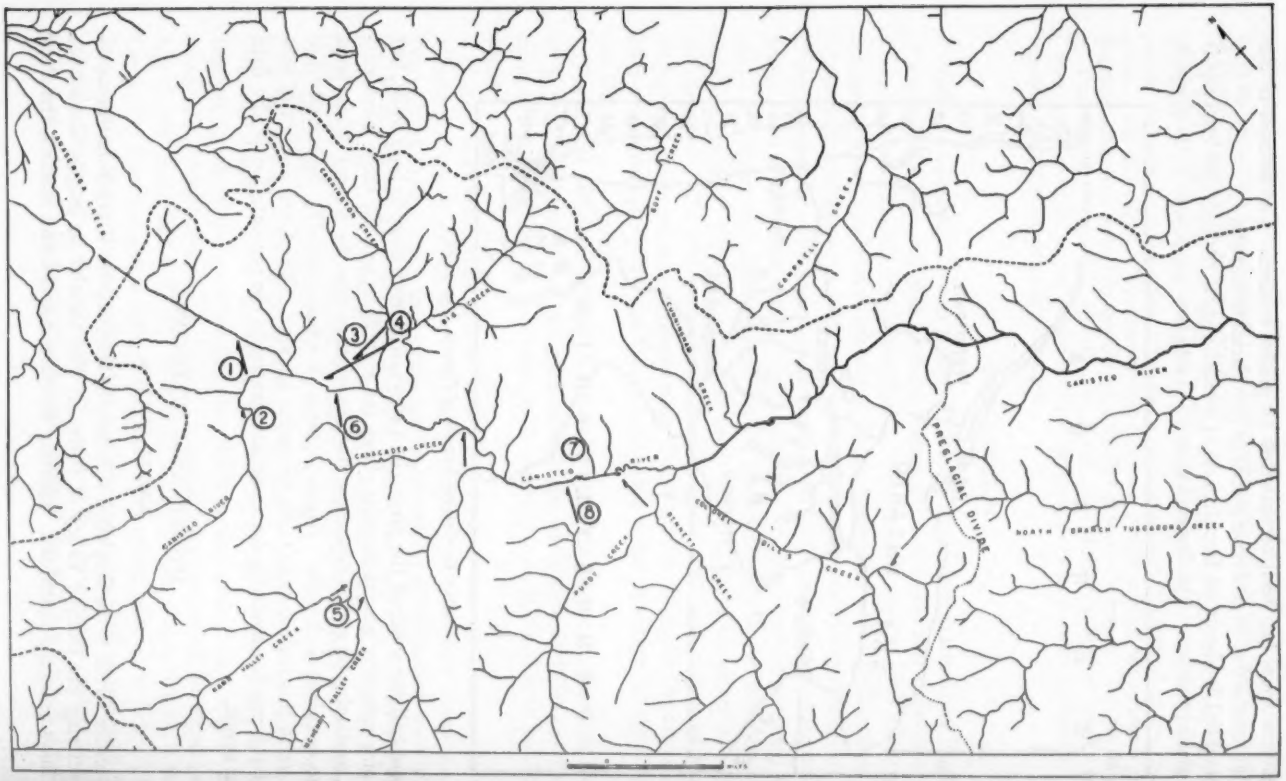


FIGURE 2.—*Drainage map of Hornell and Vicinity*

Showing present and preglacial drainage and divides, in more detail. (1) Arkport diversion, Fig. 5 and Pl. 2; (2) Bishopville diversion, Fig. 6; (3) Carrington Creek diversion, Figs. 7 and 8; (4) Big Creek diversion, Fig. 9; (5) Karr Valley and McHenry Valley Creeks diversion, Pl. 3; (6) Canaseadea diversion, Figs. 3 and 4; (7) Cunningham Creek; (8) Purdy Creek.
– – – – Present divide
. . . . Preglacial divide where different from present
Arrows show course of preglacial valleys.

makes a right angle bend to the southeast (Pl. 1). This is the Almond dam site for a flood-control reservoir being built by the U. S. Engineer Department (Fig. 3).

Upstream from the dam site, the rock valley of Canacadea Creek is about half a mile wide at stream level, although the actual topographical valley is considerably narrowed by a discontinuous terrace of glacial gravels along one or the other valley wall. Outcrops are practically non-existent along this part of the valley. Below the dam site, the valley is about half its width farther upstream, with a level flood plain about 1200 feet across, from which the hills rise steeply on both sides. The valley walls are straight, with no indication of extensive overburden deposits on either side of the valley (Fig. 3). Outcrops at intervals along both sides of this section indicate less extensive overburden than in the valley above the dam site.

At the Almond Dam site, the valley fill is about 75 feet thick (Fig. 4). The upper 3 or 4 feet of material under the flood plain consists of recent stream deposits, being in general silt and sand backwater deposits, but there are a few abandoned gravel channels. Beneath these gravels and silts is a zone, 10 to 15 feet thick, of rather coarse gravels. Below this the valley is filled with a dense, compact, bluish till, with lenses of stratified silt at or near its top.

About half a mile below the dam site is a steep bluff, where blue till rises almost vertically from the water's edge. There is a large proportion of striated limestone pebbles in this till, which is about 60 miles from the nearest outcrops of limestone. A number of rounded till buttresses stand out on the face of the bluff, rising vertically for about 30 feet, for 10 feet of which they are free of outside support. This till is apparently part of the large, firmly consolidated mass found below stream level, which formerly filled the valley.

At the top of this cliff, the blue till grades into a blue clay silt with few or no pebbles, 2 or 3 feet thick, overlain by a thin-bedded yellow sand. The silt and sand are stratified and apparently of lacustrine origin. This same condition has been encountered at several other places near Hornell.

Above these deposits, and elsewhere on the north abutment, is a loose brownish till, containing only a few foreign pebbles. In some places, this material grades into the underlying weathered and disintegrated, but undisturbed, rock, and can have in general been transported only a short distance.

Exploration in the valley of Canacadea Creek immediately above the dam site showed an extensive deposit of uniform, fine sand. The thickness of this deposit is not known, but it is at least 100 feet thick, and extends at least 30 feet below the level of the rock floor of the valley between the dam site and Hornell. These sand deposits pinch out beneath the proposed embankment of the Almond Dam, lying between the blue till and the superficial stream gravels.

North of the dam site, the straight course of the main valley is continued by a reasonably well defined high-level valley that joins the Hornell Valley at Webbs about 3 miles north of Hornell (Pl. 1). The trend shown by this section would be normal for a tributary of a northwest-flowing stream in the Hornell Valley. This portion of the Canacadea Valley is obviously a genetic continuation of that above the dam site. The valley has the same width between bedrock walls as it has near Almond and is considerably wider than the portion below the dam site. Glacial deposits, filling the abandoned valley for about 1½ miles to more than 100 feet above the

FIGURE 2.—*Drainage map of Hornell and Vicinity*

Showing present and preglacial drainage and divides, in more detail. (1) Airport diversion, Figs. 3 and Pl. 2; (2) Bishopville diversion, Fig. 4; (3) Carrington Creek diversion, Figs. 7 and 10; (4) Big Creek diversion, Fig. 9; (5) Starr Valley and Wolfberry Valley Creeks diversion, Pl. 2; (6) Canacadea diversion, Figs. 3 and 4; (7) Cunningham Creek; (8) Purdy Creek.

Arrows: Preglacial drainage, where different from present.
Arrows: Present drainage, where different from preglacial.
Arrows: Present and preglacial drainage.

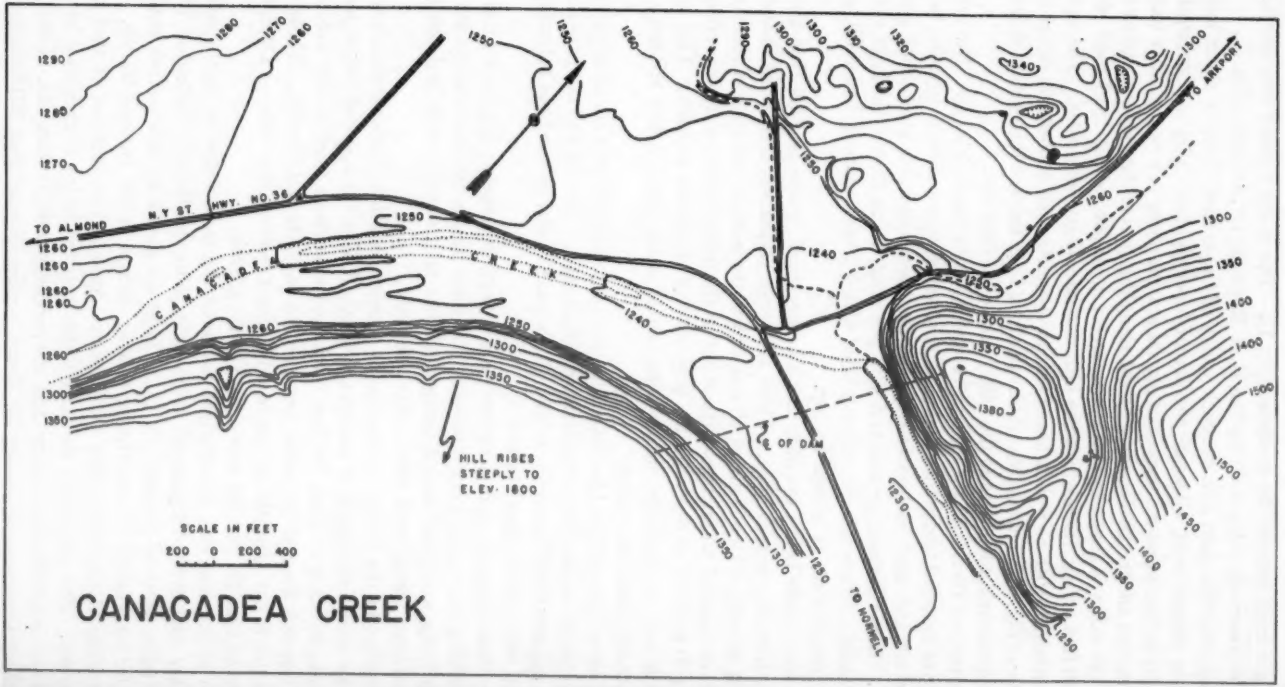


FIGURE 3.—*Contour map, Almond dam site and vicinity*

present level of Canacadea Creek, are heterogeneous mixtures of till, gravel, sand, and silt patches arranged helter-skelter. Some areas show kame-and-kettle topography.

The bedrock diversion valley at and below the Almond Dam site is nearly straight, with steep, uniform sides, and the rock floor is wide and level. The general appearance is that of a glaciated trough (Fig. 4). However, since it is nearly at right angles to the normal course of ice flow in this area, it more probably represents a valley formed by retreating waterfalls in a lake outlet, as postulated by Von Engeln (1945) for the diverted Chemung River at Elmira. About 800 feet north of the valley is a relatively narrow rock valley, with a summit near the present topographic summit, which is to be utilized for the spillway of the Almond Dam. This is topographically, and apparently genetically, similar to the lowered divides near Elmira (Tarr, 1905, p. 234, Pl. 41, fig. 1; Von Engeln, 1945, p. 108–110) and was presumably an outlet for a lake in the Canacadea Valley before the lower course, along the line of the present valley, was uncovered. Since there are no blue tills in this valley, but merely the brown ones, it probably postdates the development of the Canacadea Creek diversion valley.

A satisfactory history of Canacadea Creek must include the original diversion of the stream, followed by a period of erosion sufficient to cut a large valley; readvance of the ice with deposition of at least 50, and probably more nearly 100, feet of blue till; lacustrine conditions, at least on a local scale, during which 2 or 3 feet of clay and silt and 8 or 10 feet of sand were deposited; deposition of at least 100 feet of fine sand, which may represent the same cycle; another advance of the ice and deposition of the unconsolidated brown ground moraine; a lacustrine period, in which the spillway col served as the outlet; further melting of the ice, uncovering the present valley; a period of erosion, in which the valley of Canacadea Creek was re-excavated in the blue till to its present proportions; a period of pronounced aggradation resulting in the deposition of 10–15 feet of gravels over the entire valley floor; and, lastly, the recent period of slight aggradation with the deposition of about 5 feet of gravels along the present or past courses of the stream and of sand in the flood-plain areas. These last two surficial deposits differ strikingly from the underlying till in color, consistency, and, above all, in the large amount of water that they carry. Thus, since the excavation of the revised course of Canacadea Creek, there must have been at least two advances of the ice, one of which (the blue-till period) was of considerable significance and duration, and a considerable period of subaerial erosion must have followed the initial diversion of the stream. The col, where the spillway of the dam will be placed, apparently was cut between the last two glacial advances. The level of the rock floor of the Canacadea diversion is about 1170 feet (Fig. 4), which is too high for a course adjusted to a river flowing north on or near rock in the Hornell Valley. Therefore, it presumably was adjusted to a stream flowing in the direction of the present Canistea. If this is correct, an adequate valley slope would probably require that there be 30 or 40 feet of overburden above the rock floor at the preglacial divide near West Cameron.

FIGURE 3.—*Contour map, Almond dam site and vicinity*

PURDY CREEK DIVERSION

About 5 miles southeast of Hornell, at the southern limits of the village of Canisteo, Purdy Creek enters Bennett Creek from the west (Pl. 1). Between Canisteo and

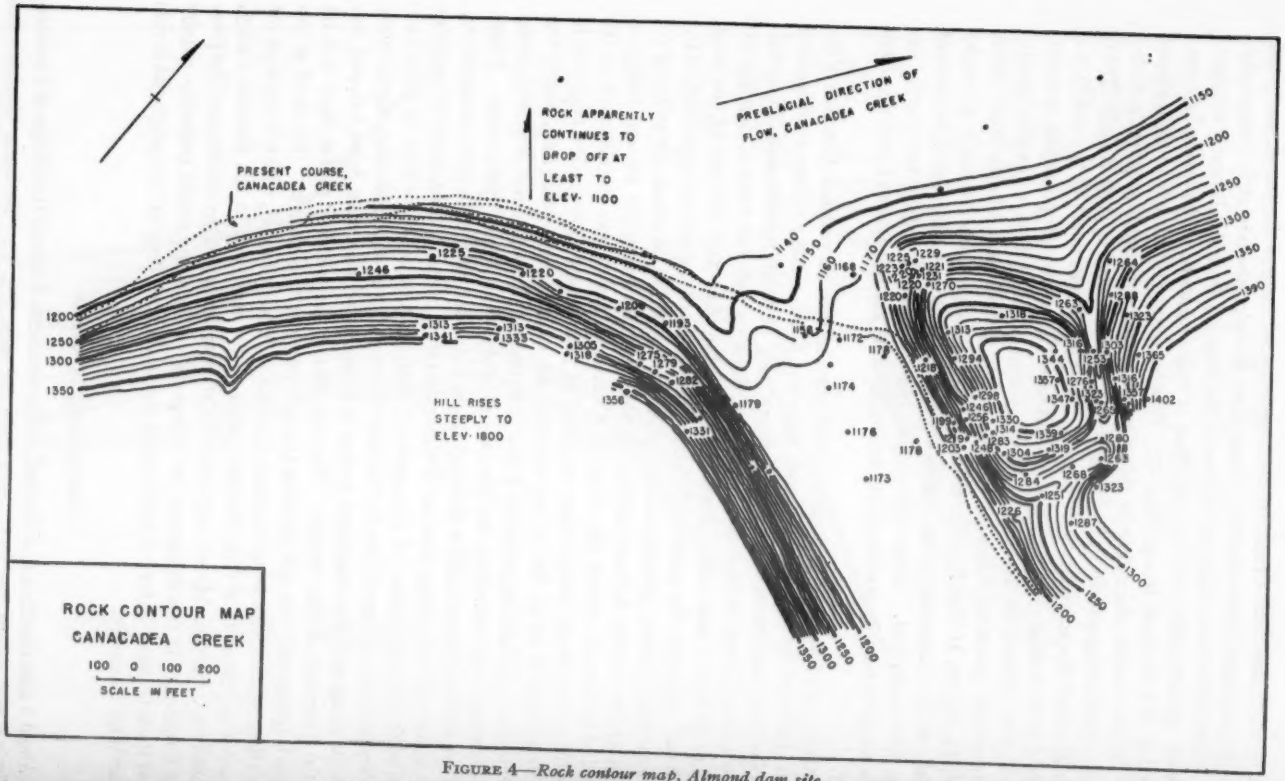

PRESENT COURSE, CANACADEA CREEK
ROCK APPARENTLY CONTINUES TO DROP OFF AT LEAST TO ELEV. 1100
PREGLACIAL DIRECTION OF FLOW, CANACADEA CREEK
HILL RISES STEEPLY TO ELEV. 1800
ROCK CONTOUR MAP
CANACADEA CREEK
100 0 100 200
SCALE IN FEET

FIGURE 4—*Rock contour map, Almond dam site*

Contours of rock surface based on drill holes (black circles) and seismic explorations.

Edgewood School, about 2 miles to the west, the Purdy Creek Valley is relatively narrow with nearly continuous exposures of rock on one side or the other. This portion of the valley makes a considerable angle with the portion upstream from Edgewood School and is about half its width. Northeast of Edgewood School, a wide, high-level drift-filled valley is a direct continuation of the upper Purdy Creek Valley. Although no subsurface explorations were made in this vicinity, it seems obvious, by analogy with the valley of Canacadea Creek and others, that this is the preglacial valley of Purdy Creek. Exposures in this valley are poor, but are largely gravel and other water-lain deposits.

Terraces of gravelly till 75 to 100 feet above present stream level extend from Bennett Creek along both sides of Purdy Creek and into the upper Purdy Creek Valley, indicating an ice advance over this section since the valley was cut. Although this valley is somewhat narrower than that of Canacadea Creek below the Almond Dam site, the difference seems proportionate to the difference in drainage areas, and both valleys were probably cut at about the same time and have had the same general history.

FIGURE 4—*Rock contour map, Almond dam site*
Contours of rock surface based on drill holes (black circles) and seismic explorations.

SINGLE-CYCLE DIVERSIONS

GENERAL STATEMENT

In contrast with the valleys of Canacadea and Purdy creeks, seven streams have been diverted from their preglacial courses much more recently. These diversions, apparently dating only from the close of the last glaciation, are on the Canisteo River at Arkport and at Bishopville, on Carrington, Big, Karr Valley and McHenry Valley, Cunningham, and Hammer creeks. All except the last two and the Bishopville diversion were potential dam sites where varying amounts of subsurface investigation were carried out.

These sites indicate more clearly than in the cases of Canacadea and Purdy creeks what the initial stages in the development of the diversion channels must have been, and a comparison of the amount of interglacial erosion on these creeks with the postglacial erosion on the creeks discussed below indicates that postglacial time has been much shorter than interglacial time, and hence that a major interglacial period must have been involved, and not merely a temporary recession of the ice front.

ARKPORT DAM SITE

The Canisteo River rises in the uplands southwest of the Hornell Valley and flows generally northeast toward Arkport (Pl. 1). The site of the Arkport retention dam constructed by the Army Engineers is about a mile west of Arkport. For a mile above the dam, the river is nearly straight, in a moderately open valley about 1000 feet wide. At the dam site, it makes a right-angle bend and enters a winding valley, only about 200 feet wide (Fig. 5). Outcrops are numerous on both sides of this narrower valley, but are in general absent in the upstream portion. Although the topography shows a winding valley, with alternating spurs and meander scars, the stream flows in a nearly straight line on a bed of unconsolidated sediments. The bends in this section appear to have been initiated by the joint planes, but subsequent meandering of the Canisteo has rounded the angles and produced several typical meander scars.

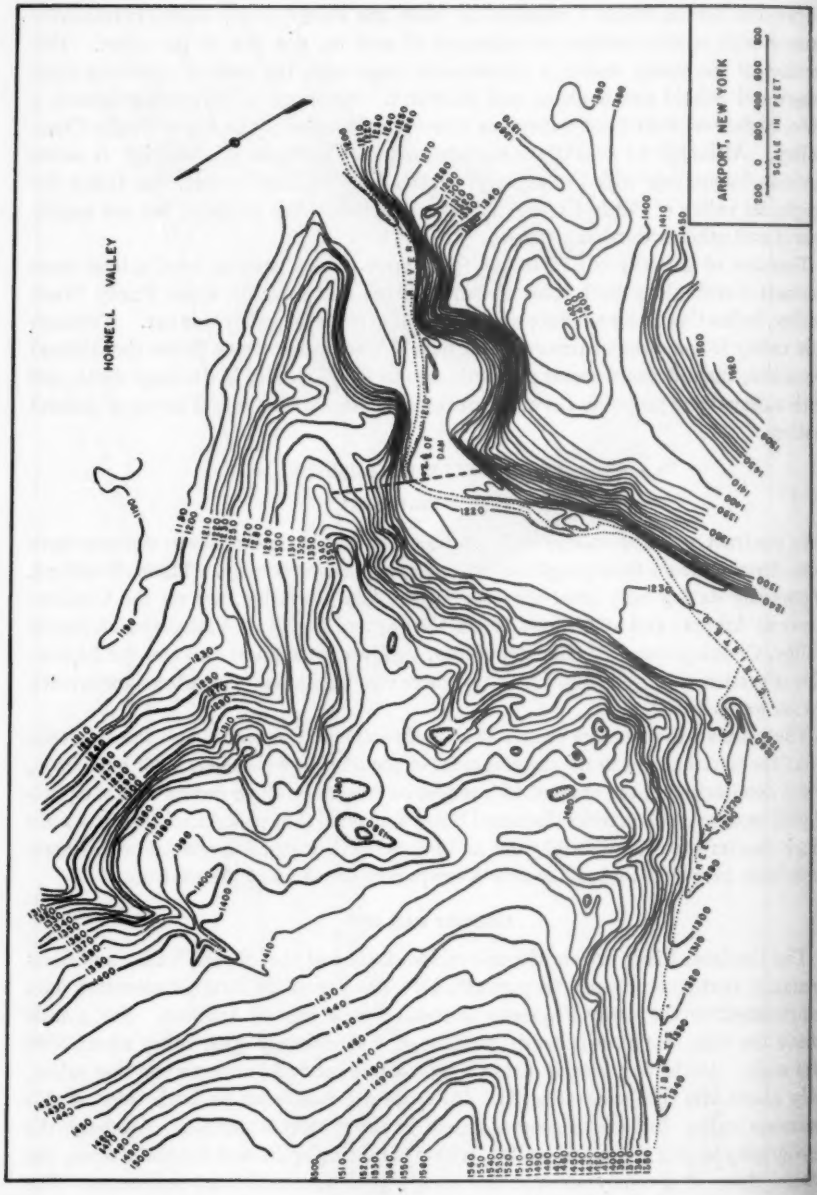
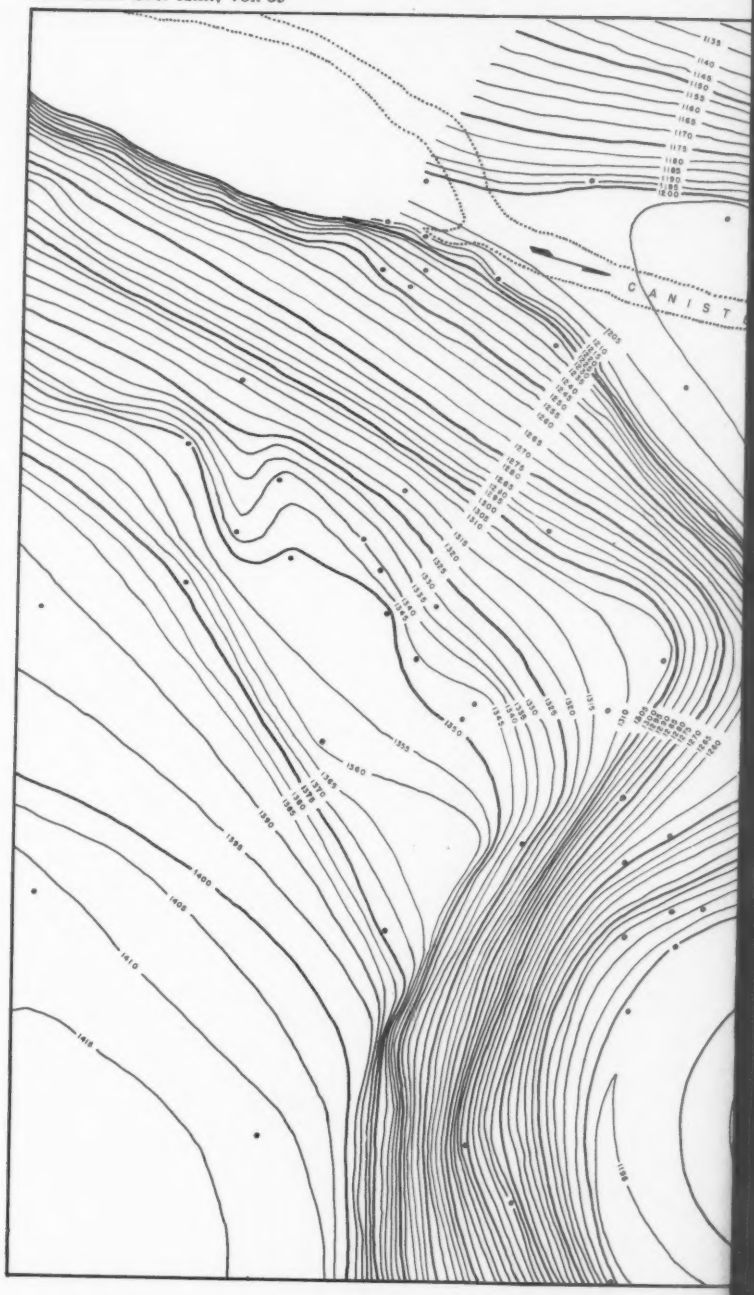


FIGURE 5.—*Contour map, Arkport dam site and vicinity*

FIGURE 5.—*Contour map, Arkport dam site and vicinity*



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Contours of roc
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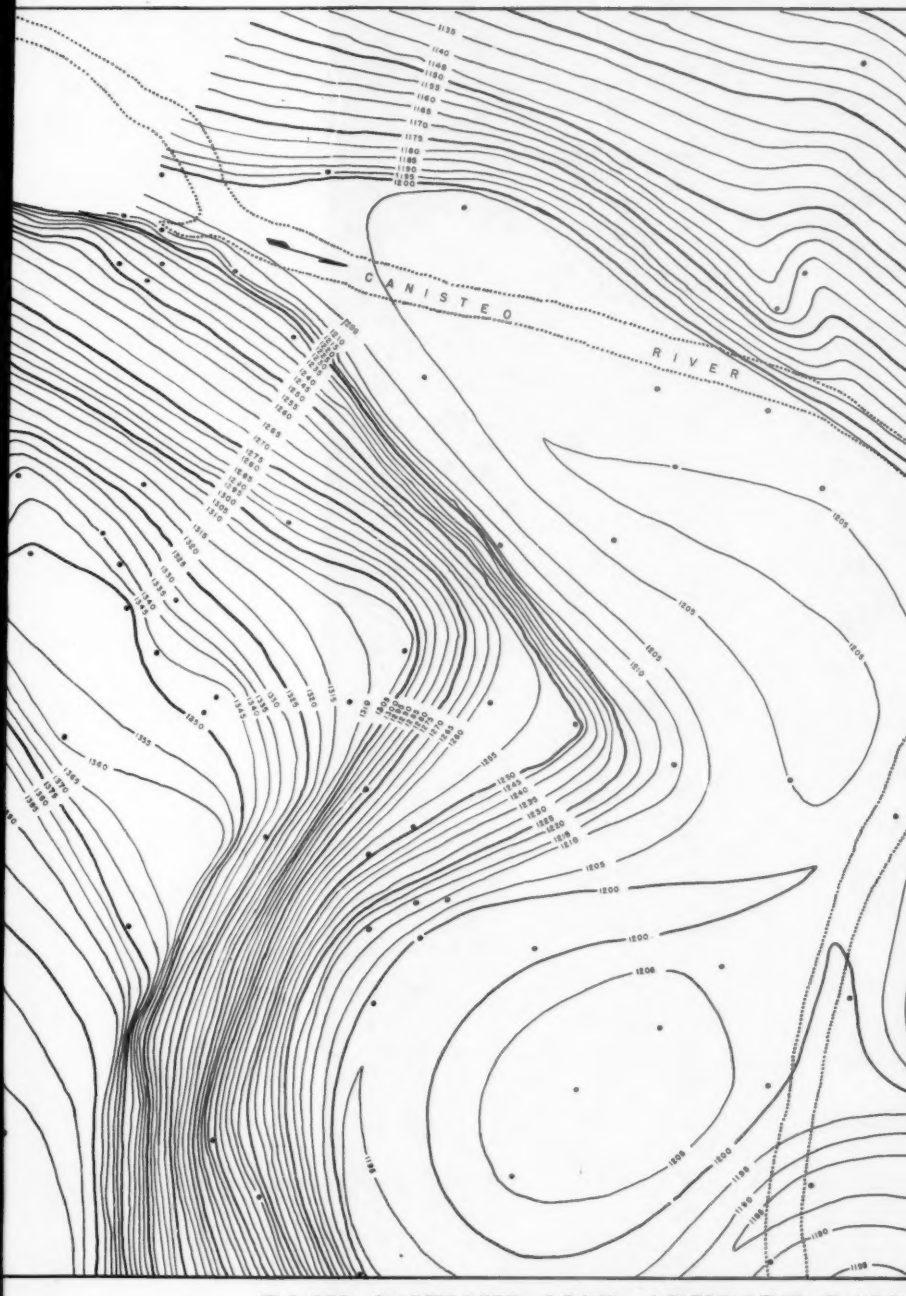


ROCK CONTOUR MAP, ARKPORT DAM

Contours of rock surface based on drill holes (black circles
seismic explorations, and excavations.

N
CONTINUES TO DROP OFF TO CENTER OF PREGLACIAL VALLEY. PROBABLE ELEVATION CA. 1000 FEET.
ARKPORT, NEW YORK
ROCK CONTOUR MAP
SCALE IN FEET
50 0 50 100 150

T DAM SITE

(black circles),
ons.

Extensive subsurface explorations for the dam showed that the deepest rock valley has a clearly marked meander pattern (Pl. 2) following the base of the visible meander scars. After this valley was cut, aggradation buried parts of the meander cores and the upper portions were planed off. The latest feature has been the formation of a shallow valley incised in rock across the neck of the first meander. This beveled the first spur on the northeast side of the valley, exposing a rock cliff.

Downstream from the center line of the dam, the overburden in the valley is relatively shallow, ranging from 10 feet above the meander cores to 20 or 30 feet over the meanders. All the material below the level of the flood plain is a uniform sandy gravel that appears to represent a single cycle of sedimentation. Above the level of the flood plain, at the base of the hillsides, a considerable thickness of somewhat modified till has been washed down onto the stream gravels from the steep slopes above.

The rock surface in the beveled spur drops rapidly to the northwest, reaching stream level at the edge of the preglacial valley. The slope of this rock surface is approximately the same as that of the rock in the eastern wall upstream from the dam site, suggesting their former continuity. Foundation exploration in the hill blocking the preglacial valley showed that the rock surface drops to the northwest so rapidly that it soon reaches depths too great to be of practical concern for dam foundations. Drilling in the preglacial valley at the upstream edge of the dam likewise showed rock to be very deep (Pl. 2). A seismograph survey finally determined the depth to the rock surface, showing the deepest part of the preglacial valley to be along the north side at a depth of about 120 feet below the present floor.

The upper few feet of overburden filling the valley upstream from the dam is stream gravel similar to that in the postglacial valley. Beneath this lies a very uniform, fine sand that rests directly on rock wherever explorations were carried out to sufficient depth to permit decision on this question. This sand is entirely different from the sediments deposited by the present cycle.

The obstruction that blocks the northeastward course of the river, and which turned it eastward, is about 1500 feet long, with a maximum height of 150 feet above stream level. The barrier is about 1500 feet wide, from the right-angle bend of the Canisteo to the Hornell Valley, and consists predominantly of a fine-grained, uniform, horizontally bedded sand with occasional pebbly beds, apparently identical with that beneath the valley floor upstream from the dam. There is a thin surface deposit of gravel on the barrier which is probably a residual gravel let down from the erosion of overlying pebbly beds.

After the melting of the ice sheet, the Canisteo River found its previous course blocked by the barrier of sand. A lake was formed as the ice melted, which spilled over at the low point. Banded deposits of blue silt and clay, about three-quarters of a mile above the dam site and extending nearly to elevation 1300 feet, were presumably deposited at this time. The gradient of the diverted portion of the river must have been very steep, since the rock at the divide was probably about 150 feet above the elevation of the Hornell Valley at Arkport, a mile away. There may well have been waterfalls in the early stages of the erosion, which would speed up the rate of downcutting (Von Engeln, 1945). The meanders, however, must have originated

from normal stream cutting. The valley fill, if any, upstream from the point of diversion would have been trenched concomitantly with the incision of the diversion channel. Even after the lake had been drained, so that the river approached its present size, reduced its rate of downcutting, and began to swing laterally, the gradient of the section from the dam site to Arkport was much steeper than at present, as is shown by the slope of the rock floor of the valley (Pl. 2). After this initial period of rapid local erosion, there was a general aggradation of the Hornell Valley, probably from rapid erosion of unstable glacial deposits in the headwater areas, which raised the local base level of the diverted channel by about 20 feet and resulted in filling the postglacial section with poorly sorted gravels, and partially obscuring the underlying meander pattern.

The present condition of the valley between the dam site and the Hornell Valley indicates that this diversion took place relatively recently. There is no evidence that the channel was cut prior to the close of the last glaciation.

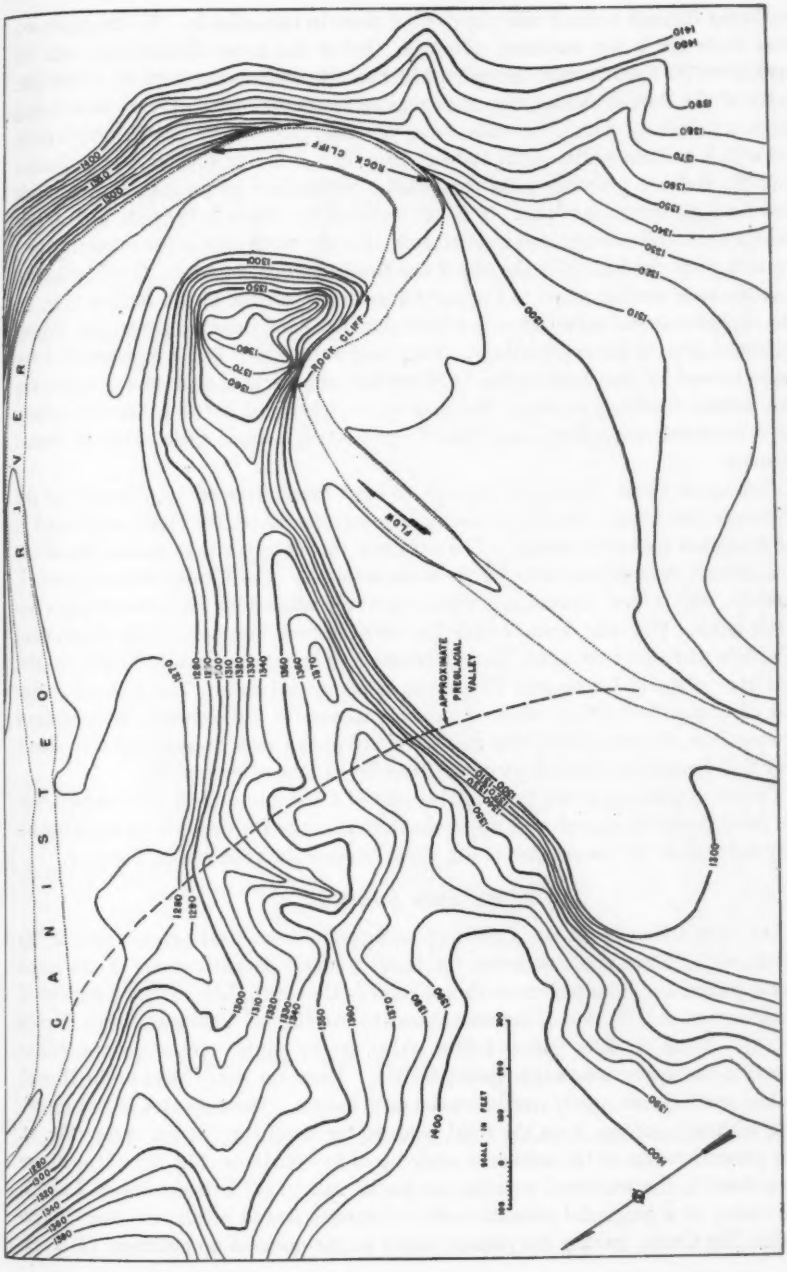
BISHOPVILLE DIVERSION

Halfway from Bishopville to Arkport, the Canisteo River bends abruptly east, at right angles to its general course. Here a ridge, 60 to 100 feet high, and from 200 to 1000 feet wide, extends about 2000 feet at right angles to the west wall of the valley, nearly blocking the valley, and apparently having blocked it at no very distant date (Fig. 6). This ridge consists of overburden except at its extreme eastern end where there are a number of outcrops. At this barrier, the stream turns and flows through a narrow gorge, with cliffs of shales and flagstones rising 80 to 100 feet high on both sides, and with a floor only about 200 feet wide. Exposures show that the rock surface on the left bank of the stream drops off abruptly to the west, disappearing below stream level about 200 feet from the eastern end of the nose. The stream soon leaves this rock gorge, and once more flows generally northeast in a wide valley with occasional outcrops. No subsurface explorations were made here, but the stream flows on rock for half the length of the gorge. Therefore the rock surface is probably within 20 feet of the present stream level in the entire trench. The presumed preglacial course of the Canisteo here is shown in Figures 2 and 6. The stream can have been flowing in its present course for only a relatively short period, since the cutting of the valley has been followed by only one cycle, during which there was limited deposition of stream gravels. Therefore, diversion must date from the close of the Wisconsin glaciation.

The Arkport diversion valley is much wider and better developed than that at Bishopville. This may mean that erosion of the upstream valley was unable to get started as soon, since sediments or a lake between the two diversions would have created a high local base level, the upper channel not being cut to any great extent until after the erosion of the Arkport channel lowered the local base level.

CARRINGTON CREEK DIVERSION

Carrington Creek is the first important tributary entering the Canisteo River from the uplands northeast of the Hornell Valley (Pl. 1). The creek flows generally


ROCK CLIFF
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ROCK CLIFF

southwest through a small valley typical of those in the uplands. In the upper sections there are a few scattered outcrops. Below the lower Hornell reservoir the creek flows for about a mile through a wider section with no outcrops on either side. South of the Burden School, the creek plunges suddenly into a narrow, meandering gorge, a mile long, with rock walls rising vertically 100 feet or more on both sides, and with a bottom width of but 100 feet (Fig. 7). A few of the curves trend about N.65°E. and are probably joint-controlled. Subsurface investigations were made here for a potential dam site. The hill south of the creek is bedrock with a thin mantle of ground moraine and residual soil. On the north side of the present valley, the rock cliffs rise nearly to the top of the Burden School terrace. Drilling showed that the rock surface drops to the northwest near the edge of the terrace (Fig. 8). The exploration was extended only a short distance back from the gorge, but showed a definite slope to lower elevations. Two farm wells, about half a mile north of the gorge, extend 220 feet to elevation 1170 feet without reaching rock, showing that the rock surface continues to drop. In the gorge, rock is about 20 feet below the surface, the overburden being dirty shaly gravel representing a single cycle of recent stream deposits.

Carrington Creek, therefore, appears to have been diverted by deposits of the Wisconsin glaciation. As in the cases previously described, the creek was forced to the southeast side of its valley. The nature of the materials that caused this diversion appears to be clearer than for the other streams. The Burden School terrace is gravelly, with a level surface approximately at elevation 1390 feet, containing a few kettle holes. Gravelly terraces near the lower Hornell reservoir at about elevation 1500 feet, and above the upper Hornell reservoir at about elevation 1580 feet, suggest that the valley of Carrington Creek was filled by outwash. The through valley east of Cream Hill (Pl. 1) shows a possible source for the outwash, from streams flowing from an ice mass to the north. Carrington Creek presumably meandered over this deposit and became incised at the edge of the outwash plain.

The exact position of the preglacial course of Carrington Creek is uncertain, but the creek probably flowed west approximately past the Burden School and presumably was joined by the preglacial Big Creek, somewhat as shown in Figure 2.

BIG CREEK DIVERSION

The next tributary of the Canisteo downstream from Carrington Creek is Big Creek, which flows west-southwest for about 5 miles, paralleling one of the major sets of joints, and then makes an abrupt bend to the south, followed by a number of sharp curves, and flows in a narrow channel to the Hornell Valley at North Hornell (Pl. 1). None of these curves follow either set of joints. Outcrops are rare or absent in the upper, westward-flowing section. From the sharp bend to the Hornell Valley, outcrops are nearly continuous on both banks. The only area of any magnitude without outcrops is on the right bank at the third bend of the creek (Fig. 9). The present course of the stream is made up of five portions (Fig. 9): (1) upstream from bend 1, the westward-trending preglacial valley; (2) between bends 4 and 3, the valley of a preglacial tributary which formerly flowed northwest into the preglacial Big Creek, leaving the present valley at the point of no outcrops; (3) a new

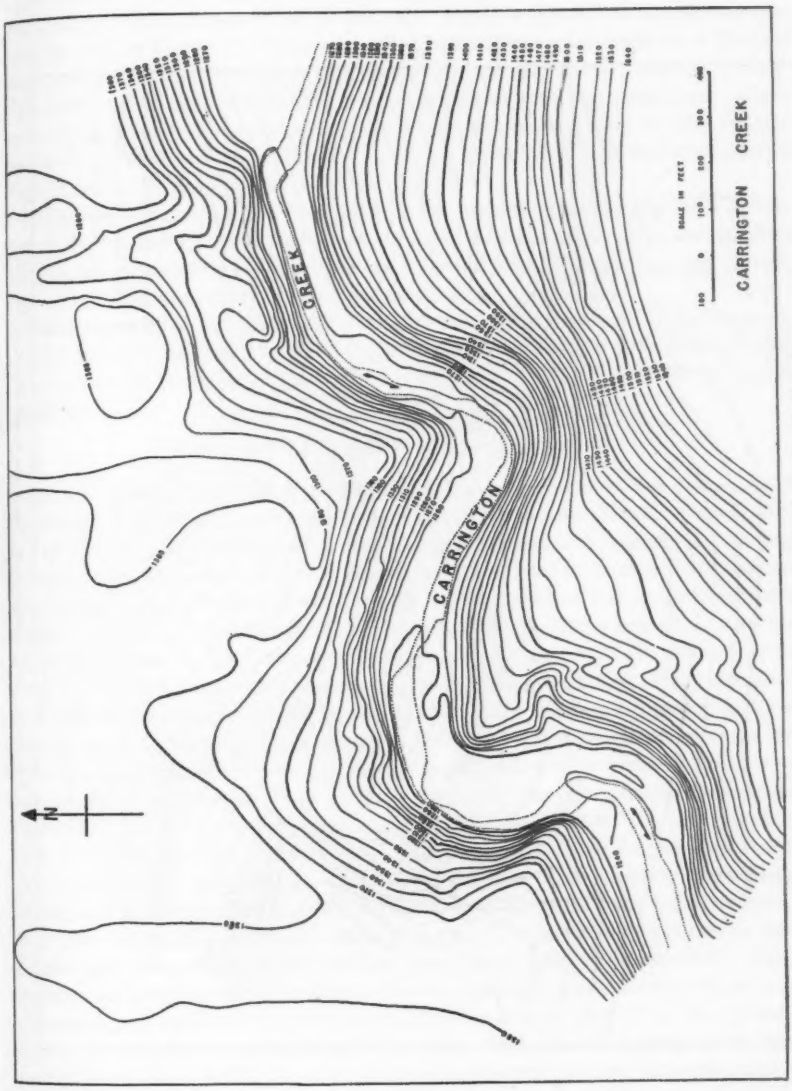

FIGURE 7.—*Contour map, Carrington Creek diversion*

FIGURE 8.—*Rock contour map, Carrington Creek diversion*

course, cut across the divide between these two valleys, between bends 1 and 3; (4) an enlarged preglacial tributary that flowed southwest to the Hornell Valley; and (5) a new channel connecting (2) and (4). Sections (4) and (5) are downstream from the edge of Figure 9. Some subsurface explorations were made for a possible flood-control dam near the upper end of the third section of this combined valley. The present valley is filled with about 10 feet of stream gravels, representing a single cycle of deposition. The south side of the valley has about 10 feet of till and slope wash over the rock surface. Three drill holes on the north side of the creek showed the rock surface to drop in that direction (Fig. 9).

No drilling was done on the ridge between the present valleys of Big and Carrington creeks, but the exposures show that the lower portions of the ridge are stratified silt and clay, apparently of lacustrine origin, while the higher portions are gravels, exposed in a large gravel pit on the top of the divide.

The narrowness of the Big Creek Valley in that portion that has been diverted, and the thinness and uniformity of the overburden deposits in the valley bottom, indicate that the diversion of this stream is recent, presumably since the Wisconsin glaciation.

KARR VALLEY AND McHENRY VALLEY DIVERSIONS

Just southwest of the village of Almond and at the border of the Hornell and Canaseraga quadrangles, two small tributaries of Canacadea Creek—Karr Valley and McHenry Valley creeks—cut narrow valleys through rock, uniting just as they emerge into the Canacadea Valley. Before turning toward each other, both streams flow east-northeast for about 6 miles in wide, joint-controlled valleys, in which both slopes are mantled by overburden (Pl. 1). These broad valleys extend, in a rather indefinite manner, to the Canacadea Valley, although they both are blocked by an extensive gravel terrace along Canacadea Creek, which Fairchild (1932) interprets as a westward extension of the Susquehanna Valley Kames. Apparently these gravels dammed the tributary streams so that they cut new courses through the lowest place in the barrier, which in both cases happened to be across the rock nose between the two valleys. Both streams now flow through narrow, meandering trenches cut in rock, with numerous outcrops and vertical cliffs (Pl. 5). The outcrops show that the rock surfaces drop off both north and south from the present streams toward the old valleys. This observation was extended and confirmed by drilling and seismic exploration (Pl. 5). The overburden in both valleys appears to be entirely gravelly outwash. Both streams follow meandering courses as they cut through the rock; the course of the meanders is not joint-controlled. These meanders are much more pronounced and have a greater horizontal extent than those at Arkport, and could not have developed after the valleys were cut to their present depths. It therefore seems reasonable to assume that streams flowing across level surfaces were intrenched from their meandering courses, as must have occurred at Carrington Creek. At that time, therefore, the upper surface of the gravel terraces along the west side of Canacadea Creek must have been level and must have extended over the area included within the meanders. In order to have developed such a level surface, the gravel must have been deposited either as outwash, filling

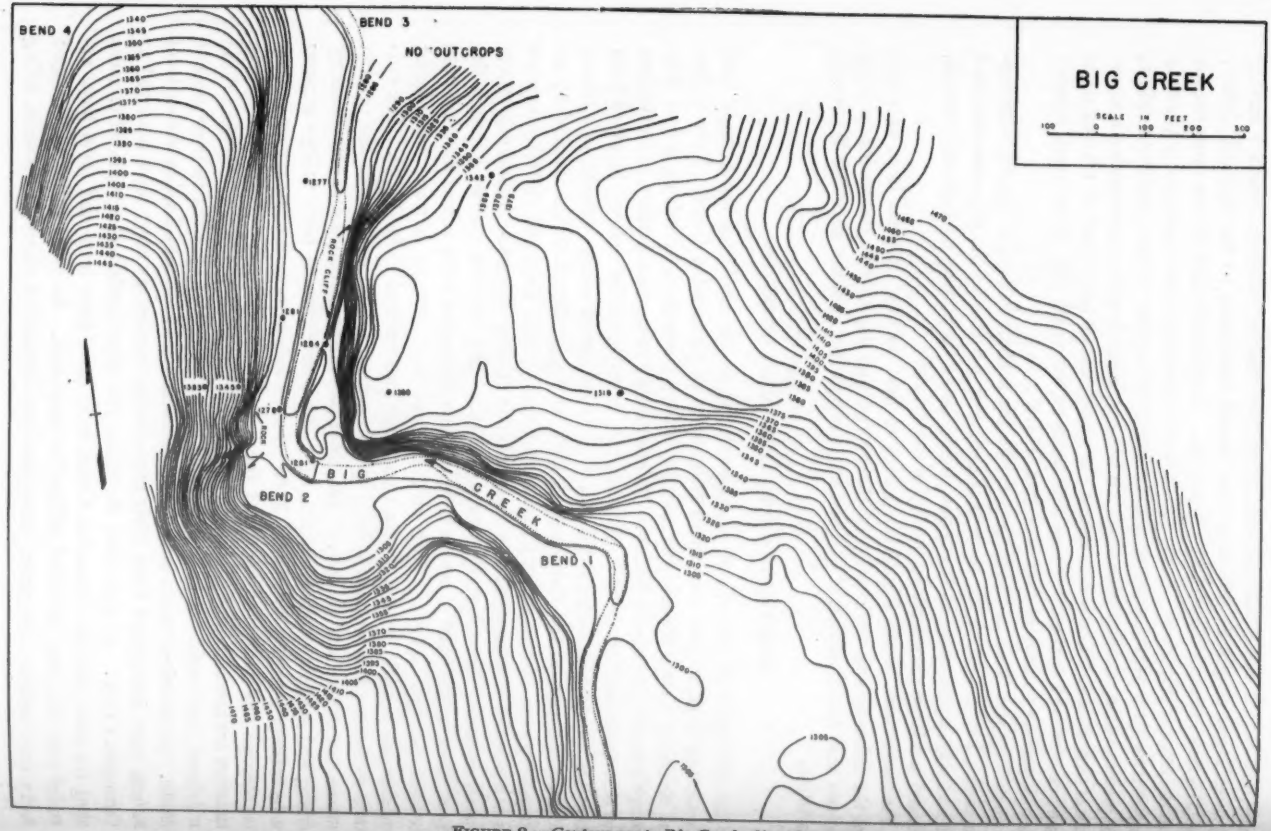

FIGURE 9.—*Contour map, Big Creek, diversion*

Showing the transition from the broad preglacial valley to the narrow postglacial one. Black circles were drill holes, with elevation of top of rock.

the Canacadea Creek Valley, or as a terrace beside an ice tongue that occupied the valley. In the former case, postglacial erosion must have removed most of the gravel. In the latter case, such erosion would have affected only a small amount of material. There must have been either a stagnant body of ice or a small lake in Karr and McHenry valleys, since the gravels do not extend far up either creek. Numerous exposures, all of limited extent, indicate that the gravel beds are nearly horizontal. This suggests a valley train that formerly filled the Canacadea Creek Valley but which did not extend into Karr and McHenry valleys because of the presence there of stagnant ice. If this interpretation is correct, there must have been very extensive postglacial erosion in the Canacadea Creek Valley, which should be associated with deposition of gravel elsewhere. It is very suggestive that the valley of Canacadea Creek, below the Almond Dam site, has a 10- to 15-foot bed of stream gravels overlain by about 5 feet of recent channel and flood-plain deposits. Explorations in the Hornell Valley at Hornell for a channel improvement project showed gravel deposits 30 to 40 feet thick. Similar deposits of postglacial gravels have been found throughout the basin of the Chemung River, of which the Canisteo is a tributary. These deposits reduce the difficulty in accepting a valley-train origin for the gravel terraces of Canacadea Creek.

In width, the diverted valleys of Karr Valley and McHenry Valley creeks are roughly comparable with the Bishopville diversion of the Canisteo. It therefore seems reasonable to believe that both date from about the same time—*i.e.*, the close of the last glaciation or later. The valleys in the present case must have been cut after the removal of much or all of the suggested valley train that filled the Canacadea Creek Valley, which probably explains why the creeks are still flowing on rock and are apparently still actively degrading.

OTHER POST-WISCONSIN DIVERSIONS

About 3 miles southeast of Hornell, Cunningham Creek enters the Hornell Valley from the north (Pl. 1). Just before it leaves the uplands, it makes an abrupt horseshoe bend to the east, flowing through a narrow gorge with rock cliffs on both sides, in marked contrast to its upper course. This diversion is very similar to the Bishopville diversion. At the upstream end, the gorge is about 60 feet wide and maintains almost a constant width. Outcrops are present at the eastern end of the barrier across the old valley. West of these outcrops, there are no exposures in the barrier, but the hill appears to be drift. At the eastern tip of the bend, the creek flows on rock for its entire width of about 30 feet. At the creek, the supposed barrier is a high, abrupt hill, due to its rock core. It changes to a mass with a morainal appearance about 100 feet west of the stream.

The lower course of Hammer Creek, a mile southeast of Cunningham Creek, shows essentially the same conditions, though the exposures are poorer.

GENERAL DRAINAGE CHANGES

At Arkport, the Canisteo River emerges suddenly from its narrow upland valley into the broad open trench of the Hornell Valley, a mile wide, with an almost level

FIGURE 9.—*Contour map, Big Creek, diversion*
Showing the transition from the broad preglacial valley to the narrow postglacial one. Black circumscribes drift hills, with elevation of top of each.

floor, to which the river is obviously underfit (Pl. 1). There are no outcrops in the Hornell Valley, except where the river is actively cutting into the valley walls, as along the east side of the city of Hornell. No information is available as to the depth of fill in this valley, but a well at a C.C.C. Camp near Arkport did not reach rock at a depth of 102 feet. This valley narrows progressively from a width of 1¼ miles at Moraine, on the low, indefinite divide between the basins of the Canisteo and Genesee rivers, southeastward across the Hornell quadrangle, and continues to narrow for 6 miles farther to West Cameron, where it is only a third of a mile wide. Below here the Canisteo Valley again flares, being two-thirds of a mile wide at the junction of the Canisteo and Tioga rivers, about 18 miles below the narrowest point at West Cameron.

As has been pointed out by Fairchild (1925, p. 40, 41, 87) and Von Engeln (1945, p. 118), this part of the Canisteo Valley apparently owes its present condition to a reversal of direction. Between West Cameron and Moraine, the stream apparently drained north in preglacial times but was reversed in direction by glacial erosion, deposition, ice dams, or a combination of these factors.

In the area studied, the present divide between the Genesee and Canisteo River basins lies between 1195 and 2340 feet above sea level. The divide between the Canaseraga Creek portion of the Genesee basin and the Canisteo River reaches only elevation 2120 feet, and less than 2 miles of it is above elevation 2000 feet. Along the supposed preglacial divide (Fig. 2), the uplands are appreciably higher than those either along the present divide or downstream from the presumed preglacial divide. At the former divide, the contours do not drop below elevation 2000 feet except in the immediate vicinity of the Canisteo Valley. While the maximum elevation is about the same as that along the present divide, the former divide averages about 200 feet higher than does the present one. Plate 1 shows that the upland surface slopes both ways from the presumed preglacial divide. The drainage, the present divide, and the preglacial divide are shown on Figure 2.

There are a series of well-developed high-level terraces between Canisteo and West Cameron (Pls. 3, 4). Just east of Canisteo, there is a bench on the south side of the valley about two-fifths of the way up the valley wall (Pl. 3). At Adrian, it is about three-fifths of the way up (Pl. 4, fig. 1). About 2.5 miles east of Adrian, the bench is visible just below the uplands (Pl. 4, fig. 2), and shortly beyond this all traces of it disappear. Farther downstream, a similar change of slope can be found in the downstream portion of the Canisteo, which appears at Cameron (Pl. 4, fig. 3). The bench at Canisteo coincides with the top of the Dunkirk sandstone and was identified by Bradley and Pepper (1938, Pl. 4A) as a structural terrace. From their data, the other terraces as far east as the presumed preglacial divide would be within 100 feet of the top of the Dunkirk and might be related to it. However, there does not appear to be any stratigraphic control possible in the region around Cameron, since the Dunkirk is here considerably higher. The stratigraphic data are by no means clear in this area, and, while these terraces may merely represent the top of the Dunkirk rising to the east, they may be the remnants of a valley floor, which would form a graded channel plunging below the Hornell Valley somewhere between Canisteo and Hornell.

FIGURE 1. CANISTEO RIVER
Looking downstream from bridge on N. Y. State Highway 17F at mouth of Bennett Creek.

FIGURE 2. BENNETT CREEK AND CANISTEO RIVER VALLEY
Looking downstream from bridge across Bennett Creek on N. Y. State Highway 21.

CANISTEO VALLEY BETWEEN CANISTEO AND WEST CAMERON

Remnants of high level valley marked "A", later notch marked "B".

FIGURE 1. LOOKING DOWNSTREAM
From N. Y. State Highway 17F, 8 miles northwest of Cameron, at Adrian.

FIGURE 2. LOOKING DOWNSTREAM
From N. Y. State Highway 17F, 4 miles northwest of Cameron and 2½ miles southeast of Adrian.

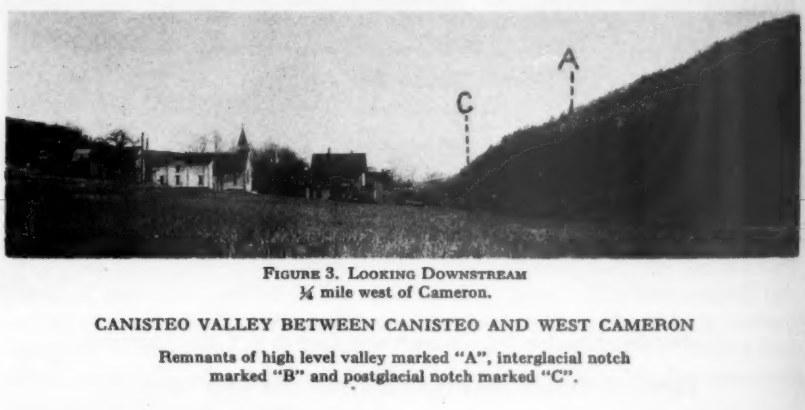

FIGURE 3. LOOKING DOWNSTREAM
¼ mile west of Cameron.

CANISTEO VALLEY BETWEEN CANISTEO AND WEST CAMERON

Remnants of high level valley marked "A", interglacial notch marked "B" and postglacial notch marked "C".

About 2.5 miles east of Adrian, the valley wall clearly shows three slopes (Pl. 4, fig. 2). The upper one is interpreted as the slope of the preglacial headwaters, nine-thenths of the way from the present stream level to the uplands. The lowest one is the slope cut by the present stream under present conditions. The middle one is interpreted as being perhaps the only visible remnant of an interglacial valley that had established a somewhat different regimen from that of the present Canisteo River.

From Moraine to the preglacial divide at West Cameron, 37 creeks enter the Hornell Valley. Of these, 4 flow in a direction that is normal for tributaries of a north-flowing stream, 14 show a slight tendency in this direction, 9 enter the Valley almost at right angles to its direction at the point of entrance, 5 (all small) have a direction of flow normal for the present direction of drainage, and 5 of the largest tributaries (the Upper Canisteo, Canacadea Creek, Carrington Creek, Big Creek and Purdy Creek) at present follow courses definitely adapted to that of the Canisteo River. In each case, the stream is connected to the Hornell Valley, upstream from the point where it debouches at present, by a high-level valley. These streams would definitely be adapted to a north-flowing stream if they now occupied the high-level valleys.

SUMMARY

(1) Numerous streams near Hornell, N. Y., obstructed by glacial deposits, have cut new valleys for themselves, to the south or southeast of their former courses.

(2) These valleys are of two sizes, one of which contains nothing but recent stream gravels, whereas the other contains 60 feet or more of glacial deposits. These data suggest that the former set were cut in postglacial times and that the latter were cut during an interglacial period. Since the interglacial valleys are much wider than similar streams have been able to make their postglacial valleys, interglacial time must have been much longer than postglacial time has been.

(3) In addition to the two glacial advances represented by the superficial tills and the earlier blue tills, there must have been an earlier advance, which caused the initial diversion of Canacadea Creek and perhaps of Purdy Creek. No deposits of this glacial advance have been identified, though obviously the core at least of the barriers blocking the preglacial valleys of these streams must belong to such a period.

(4) There has been extensive deposition of stream gravels along all the creeks of the area since the melting of the ice.

(5) The drainage basin of the Canisteo River above West Cameron drained north in preglacial times, into the basin of the Genesee River.

(6) The preglacial relief was at least 100 feet greater than the present relief, owing to the extensive deposits of overburden now filling the valleys.

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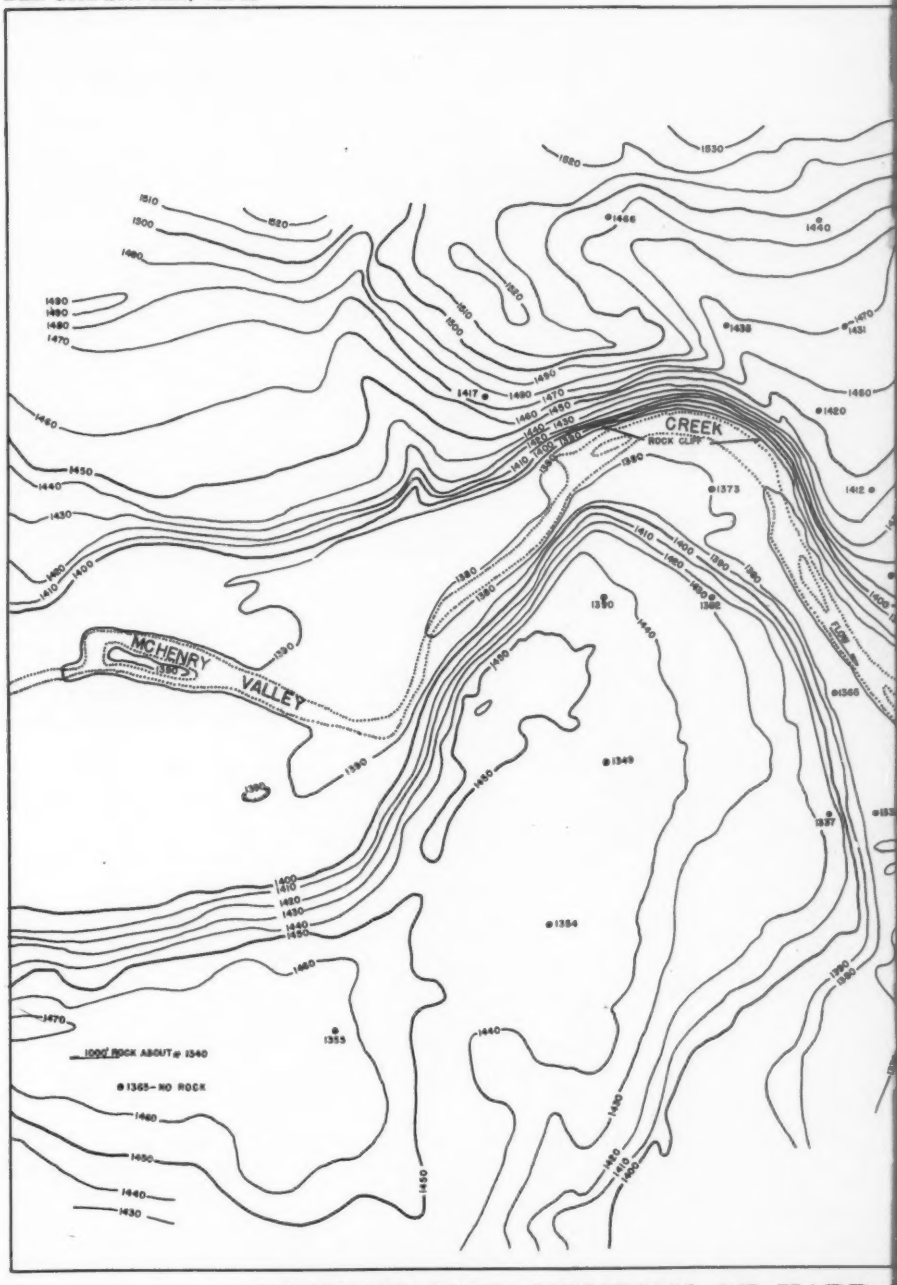
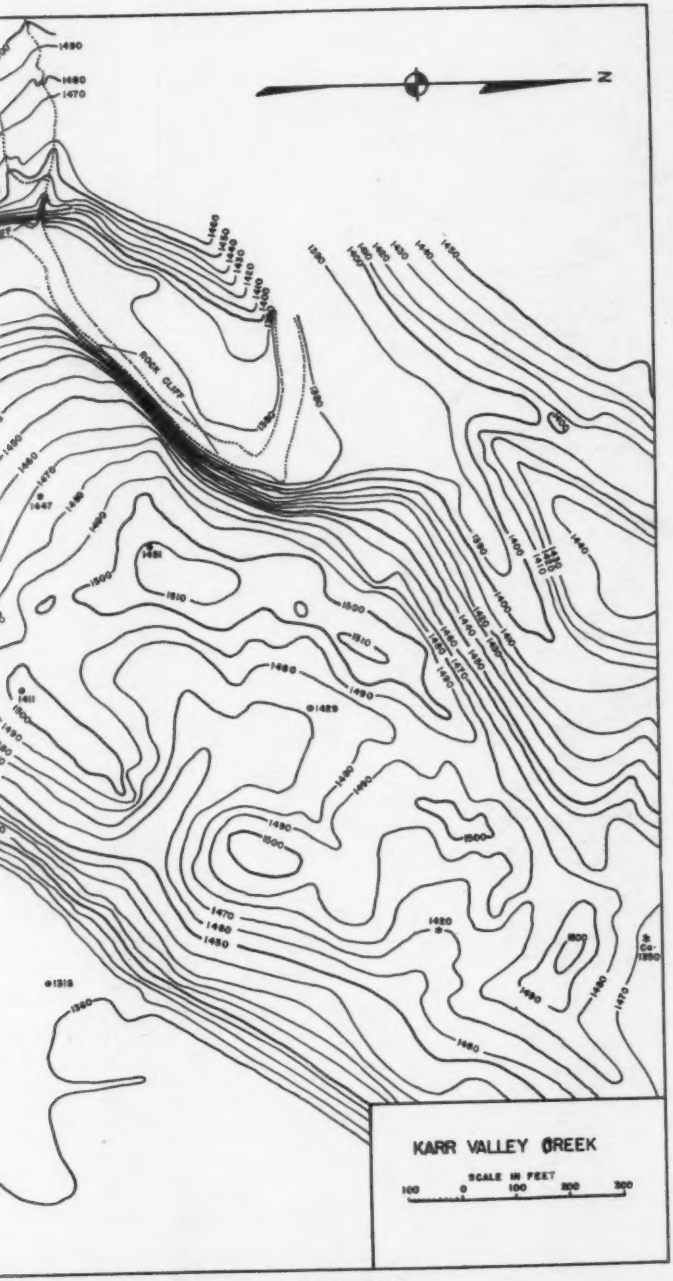


CONTOUR MAP, JUNCTION OF KARR

Black circles represent drill holes with top of rock at eleva

CTION OF KARR VALLEY AND McHENRY V

oles with top of rock at elevation shown. Asterisks show elevations deter



ENRY VALLEY CREEKS

evations determined by seismograph.

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ABSTRACTS OF PAPERS PRESENTED AT THE MEETING IN NEW YORK, NOVEMBER 11, 12, and 13, 1948

LARAMIDE DEFORMATION IN THE GREENHORN MOUNTAINS, GRANT COUNTY, OREGON

RHESA M. ALLEN, JR.

Virginia Polytechnic Institute, Blacksburg, Va.

The Greenhorn Mountains, a part of the Blue Mountains of Eastern Oregon, consist of Carboniferous argillites and greenstones intruded by Jurassic (?) gabbro and ultramafics and by late Jurassic or early Cretaceous biotite-quartz diorite. The diorite mass, known as the Greenhorn batholith, constitutes the center of the Greenhorns and is a westward continuation of the Bald Mountain batholith of Baker County. A zone of west-northwest shearing may be traced for 7 miles through the northeast part of the diorite body and through the older sedimentary and igneous rocks.

In detail the shear zone is composed of a major strike-slip fault of west-northwest trend, several smaller northwest strike-slip faults, and north-northeast high-angle reverse faults. Along the major strike-slip faults and the smaller northwest strike-slip faults, the southwest blocks have moved relatively southeast, and the fault surfaces dip northeast. The high-angle reverse faults are seemingly confined to the southwest margin of the shear zone. All faults contain dikes of quartz diorite porphyry, quartz monzonite porphyry, and granophyre. Petrographically the dikes are similar to the early Tertiary dikes cutting the Idaho batholith, and border relations between the dikes and the Greenhorn batholith indicate considerable erosion and chilling of the latter before dike emplacement.

As the late Mesozoic-early Tertiary, or Laramide, orogenic disturbance has been recognized in the Wallowas and within the Idaho batholith, the presence of a major shear zone cutting the Greenhorn batholith and its associated aplites and pegmatites, and the presence of porphyry dikes of a probable early Tertiary age, suggests that the genesis of this structure is associated with the Laramide orogeny.

BAUXITIZATION AND RESILICATION*

VICTOR T. ALLEN

St. Louis University Institute of Technology, St. Louis, Mo.

This paper summarizes the results of the writer's investigations of bauxite and high-alumina clay deposits of the United States under the auspices of two State Geological Surveys, under a grant from The Geological Society of America in 1941, and as Commodity Geologist, United States Geological Survey from 1942–1946. Three processes are recognized; in order of their importance they are: (1) desilication, in which silica is removed from clays, feldspars, and other aluminum minerals; (2) migration of clay minerals and hydrous aluminum oxides; (3) resilication, which is the union of silica with gibbsite to form clay. Preservation of the structure of sedimentary clays and the presence of transitional zones of clay retaining structures of the parent rocks indicate that most bauxite and diaspore deposits of the United States have formed from clay or that clay was an intermediate stage in their formation. Veins of clay minerals cutting bauxite do not prove resilication, particularly where clays overlie bauxite, because migration of clay minerals has occurred at many deposits not associated with bauxite. Migration of hydrous aluminum oxides may form zones and nodules that lack texture of the parent rock. The occurrence of cellular kaolin in Georgia suggests its formation by addition of silica to gibbsite (resilication) rather than by migration of kaolinite. Although resilication has operated at some deposits, most of the large kaolinite deposits of the United States are of sedimentary origin and were not formed by resilication.

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MONZONITE INTRUSION AND MINERALIZATION IN THE COEUR D'ALENE DISTRICT, IDAHO

ALFRED L. ANDERSON

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The monzonite, to which the mineralization in the Coeur d'Alene district, Idaho, is thought to be genetically related, apparently was intruded as a hornblende-augite diorite. Because of later introduction of potash-bearing emanations from below, potash feldspar, particularly microcline, was added in abundance; and the original, moderately basic rock was largely transformed to alkalic monzonite and syenite. During late stages, the emanations became somewhat sodic, and some albite was formed. Introduced with the emanations were the constituents which gave rise to considerable amounts of sphene, apatite, magnetite, and locally garnet, and minor amounts of other minerals.

Elsewhere along zones of faulting where monzonitic rocks are not exposed but whose source equivalents are presumed to occur at depth, the country rock (Belt series) has been extensively bleached (sericitized). This alteration very likely resulted from the action of potash-bearing solutions which passed into the cooler rocks above the source region where conditions favored the formation of sericite rather than the higher-temperature feldspars. Locally the bleached zones were invaded later by ore-bearing solutions which first induced further, more intense sericitization along channelways and then deposited siderite, quartz, and the metalliferous minerals.

The potash introduced into the nearly consolidated intrusives and the invaded rocks presumably evolved as a differentiation product of a deep source magma. This implies that the course of differentiation was toward the formation of alkalic solutions during late magmatic and ore stages.

PROBLEMS OF CORRELATION IN THE PECAN GAP CHALK (UPPER CRETACEOUS) OF CENTRAL TEXAS

I. J. ANDERSON

The University of Texas, Austin, Texas

The Pecan Gap chalk (Taylor group, Upper Cretaceous) has been mapped (Ellisor and Teagle, Stephenson) as a narrow outcrop, extending from White Cliffs, Arkansas, across northeast Texas to Delta County, then southward into Medina County. It has been considered as an overlapping unit (Ellisor and Teagle) and divided into three microfaunal zones. It also has been thought to be a facies equivalent of units such as the Annona chalk and the Anacacho limestone (Stephenson).

Carefully selected exposures of the Pecan Gap chalk and contiguous strata of the Taylor group have been studied and sampled. These samples, taken at small intervals in the measured sections, will be used to establish a foraminiferal zonation of the Pecan Gap chalk; and along with the observed field relations of the beds, it is hoped that this zonation will help solve the problems of correlation in these beds.

BUNGER'S "OASIS", ANTARCTICA*

EARL T. APFEL

210 Buffington Rd., Syracuse, N. Y.

Bunger's "Oasis" near latitude 66°07′ S. and Longitude 100°56′ E. in Antarctica was discovered on U. S. Navy Operation Highjump and revisited as part of a mission of U. S. Navy Task Force 39 in January, 1948. This 12- by 30-mile ice-free land, lying in the area usually mapped as part of the Shackleton Shelf, was formerly intensely glaciated. The present glaciers which flow past the "oasis" are deflected from the area by land which was formerly ice-covered.

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Deflection of glacial drainage around the area, low humidity and low snowfall, together with high insulation in the summer keep the area ice free. The waters of numerous rock-basin and moraine-dammed lakes are salty, and an efflorescence of salt appears on the surface, especially around the lakes.

The bedrock is obscured by morainic deposits over considerable areas, but is exposed on the steeper slopes and higher hills. Gneisses, very much altered by granite magma, are the principal rocks found in place, but a variety of other rocks were collected from the drift. Among these, several hypersthene-bearing rocks belonging to a charnockite series may represent the terrain farther inland.

ANTARCTIC ROCK (EXHIBIT)*

EARL T. APFEL AND WEI TA HUANG

Syracuse University, Syracuse, N. Y.

A collection of rock types from the margin of the Antarctic continent at several places yielded igneous and metamorphic rocks of some variety. Chosen for exhibit are representative specimens collected between 90° and 110° E. Longitude.

The igneous rocks include two main groups; one is holocrystalline, and the other fine-grained to aphanitic. The former range from acid to basic, with hypabyssal representatives. The latter, intruded into the older metamorphic and igneous series, include aplites, lamprophyres, and basalts.

Metamorphics from original igneous and sedimentary rocks appear to have been regionally altered. Of particular interest is a charnockite series which includes acid, intermediate, and basic members.

GEOMORPHIC RELATION OF THE ROCKY MOUNTAINS

WALLACE W. ATWOOD AND WALLACE W. ATWOOD, JR.

21 Otsego Road, Worcester, Mass; 109 Brookside Dr., Chevy Chase, Md.

In 1937 we presented a paper entitled *Working hypothesis for the physiographic history of the Rocky Mountain region*. This paper was published in the Bulletin of The Geological Society of America in June 1938. We have continued our studies although interrupted somewhat by war work and now wish to relate the physical evolution of the mountain area to that of the Great Plains to the east and the Plateaus to the west.

Our studies have been extended into the Canadian Rockies and into the physiographic provinces adjoining the Rockies in the United States. Special attention has been given to the extension of the great erosion surfaces in the mountains and to the vast amount of material carried from the mountains and distributed over the adjoining lands.

We believe definite correlations can be established between the geomorphic history of the mountains and the physiographic histories of the Great Plains to the east and the Plateaus to the west. We will report latest field observations and our working hypothesis for this larger problem.

URANIUM MINERALS FROM THE HILLSIDE MINE, YAVAPAI COUNTY, ARIZONA

JOSEPH AXELROD, FRANK GRIMALDI, CHARLES MILTON, AND K. J. MURATA

U. S. Geological Survey, Washington, D. C.

A mineral assemblage, forming coatings on gypsum at the 300-foot level of the Hillside mine, contains a variety of hitherto unknown uranium minerals, together with schroeckeringerite, pre-

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viously known only from Wyoming and Czechoslovakia. The new minerals are bayleyite, $Mg_2UO_2(CO_3)_3 \cdot nH_2O$; andersonite, $Na_2CaUO_2(CO_3)_3 \cdot nH_2O$; and swartzite, $CaMgUO_2(CO_3)_3 \cdot nH_2O$. There are also two other new unnamed substances which are dehydration products of bayleyite and swartzite. Bayleyite, swartzite, and andersonite have been synthesized. Analyses, optical data, and X-ray patterns of the new minerals are given together with X-ray patterns of the dehydration products. Schroeckeringerite has been analyzed and its formula found to differ from that given in the older accounts in the literature; our analysis agrees closely with that of the Wyoming schroeckeringerite recently reported by Jaffe, Sherwood, and Peterson.

PRESENT STATUS OF COAL MINING GEOLOGY

(Report of the Mining Geology Subcommittee of the Coal Research Committee, SEG)

CLAYTON G. BALL

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One of the most important problems facing coal-mining planning, geology, and production today is that of specific knowledge concerning our coal reserves—their quality, thickness, and mining characteristics. A realistic approach and a rapid reappraisal are urgently needed. Both the Coal Resources Subcommittee of the National Bituminous Advisory Committee and the Coal Division of the A.I.M.E. are formulating initial plans of procedure for analyzing and attempting to provide the answers to this problem.

Coal-mining geology is providing assistance, though not as much as might be desirable, in such aspects of production as exploration of virgin or partially mined reserves, both underground and stripping, by drilling, examination of aerial photographs, etc.

OUACHITA FACIES IN CENTRAL TEXAS

VIRGIL E. BARNES

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Steeply dipping shales and interbedded sandstones presumably of the Ouachita facies have been discovered along the Colorado River in Burnet and Travis counties, Texas. Previously the Ouachita facies was known in Texas only from bore-hole samples. The outcropping rocks are not metamorphosed, whereas many of the bore-hole samples described in the literature are metamorphosed. A re-examination shows that the bore-hole samples nearest the outcrop lack metamorphism except for slight changes along slickensides, whereas away from the outcrop the rocks are progressively more metamorphosed until in Caldwell County, the farthest point reached, the rocks are schist. Lithologies and grade of metamorphism suggest that the Caldwell County bore holes enter the Ouachita facies rather than rocks of pre-Cambrian age.

ELECTRON MICROSCOPY OF THE KAOLIN MINERALS

THOMAS F. BATES, FRED A. HILDEBRAND, AND ADA SWINEFORD

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The development of the electron microscope has made possible detailed morphological studies of the clay minerals.

Nacrite, dickite, and some kaolinites have been effectively studied with the petrographic micro-

scope because of their relatively large, well-defined crystals. Endellite, halloysite, and allophane particles can be observed in detail only at magnifications greater than 5000 diameters.

Kaolinite crystals from different localities show appreciable variation in size but in only a few instances depart from the characteristic pseudo-hexagonal shape.

Endellite and halloysite crystals, previously described as "lath-shaped", are actually slender hollow tubes which show a considerable diversification in both shape and size. The tubes are essentially cylindrical but in many cases are partially or completely flattened into ribbons. They are commonly split lengthwise and are often "unrolled" to a varying extent. Two, or occasionally more, concentric tubes are frequently observed.

Allophane particles are irregular in shape, but similarity to some of the poorly crystallized halloysites suggests the possibility of a transition between these two minerals. Morphological evidence of the presence of intermediate members in a kaolinite-halloysite series is lacking.

Previous electron microscope work by the writer on the illite minerals (hydromicas) has shown that morphological differences are directly related to the geological history of the rock in which they occur. The present work suggests that variations in the morphology of the kaolin minerals can be related to the mode of formation and subsequent history of the clay.

GLACIAL EVOLUTION OF THE GRAND RIVER IN MICHIGAN

STANARD G. BERGQUIST

Michigan State College, East Lansing, Mich.

Grand River, Michigan, owes its development largely to the wasting of the ice in the Saginaw lobe during the Cary substage (Wisconsin). From its headwaters, centered in the Mississinawa moraine, the river flows northerly to Lyons; here it turns abruptly westward and flows into Lake Michigan at Grand Haven.

The river developed as two segments with the upper and lower reaches originating simultaneously with the retreat of the Saginaw lobe. The two segments joined when the ice retired to the Lyons moraine, the fifth of a series of seven slender ridges of the Saginaw deployed group. The upper end of the river was merely a tributary of the west-flowing lower segment which eventually extended its headwaters eastwardly into the Maple River valley.

At each temporary halt of the retreating ice the growing upper unit of the stream was blocked to the north and forced to follow a course along the stationary ice front. Throughout the stages of development it became integrated with a number of major river systems, the glacial waters of which were directed west and finally into the Mississippi.

The lower unit of the glacial river, from Lyons to its outlet, lengthened westwardly as the Saginaw ice retreated and finally merged with the Maple River whose headwaters reached into the Saginaw Basin. This section served successively as the major line of discharge for glacial lakes Maumee, Arkona, Whittlesey, and Warren. The large volume of discharge through this channel is reflected in the lack of adjustment between the present river and the overdeveloped valley through which it flows.

When the channel ceased to function as a drainage way for the glacial lakes the Maple River was relegated to a tributary of the Grand River whose two segments became integrated.

FOSSIL SEEDS FROM SOUTH CAROLINA

E. WILLARD BERRY

Duke University, Durham, N. C.

Thirty-three species of fossil seeds have been found in buried swamp deposits under the spillway section of the Santee Cooper Project—Santee River Dam in South Carolina. These seeds represent

about 30 genera. With one exception the flora is comparable to a present swamp and near-swamp flora. The exception is *Juglans cinerea* L. which might well have floated in from the mountains upriver.

X-RAY MEASUREMENTS ON VAUQUELINITE

L. G. BERRY

Queen's University, Kingston, Ontario

New observations on vauquelinite crystals from Beresovsk, Urals, yield the following data: Monoclinic, $P2_{1/n}$. The unit cell, with $a = 13.68$, $b = 5.83$, $c = 9.53$ Å, $\beta = 93° 58'$, $a:b:c = 2.3465:1:1.6346$, contains $(Pb, Cu)_{12}[(Cr, P)O_4]_8$. Specific gravity 6.06 (measured, Dana), calculated 6.03 for $4[Pb_2Cu(CrO_4)(PO_4)]$. A well-marked pseudo-cell with half the volume of the true cell and $2a' = [101]$, $b' = b$, $2c' = [\bar{1}01]$ has the same orientation and axial ratio as the morphological unit chosen by Goldschmidt.

FLOW OF HEAT IN THE FRONT RANGE

FRANCIS BIRCH

Harvard University, Cambridge, Mass.

During the construction of the Alva B. Adams (Continental Divide) Tunnel, 13 miles long, under Rocky Mountain National Park, geologists of the Bureau of Reclamation obtained about 70 measurements of temperature at tunnel level (about 8300 feet above sea level). These observations have been reduced with the purpose of finding the flow of heat in this region. Corrections have been applied for the topography on several different hypotheses regarding the physiographic history. The corrected gradient lies between 24.8 °C/km, on the assumption that the present topography has persisted indefinitely, and 20.3 °C/km, on the assumption that the surface features have been derived from an old-age surface by uniform uplift and erosion during the last million years. If the time of evolution is taken as 4 million years, the corrected gradient is 22.0 °C/km. An uncertainty of about ±1 °C/km results from lack of reliable data concerning the surface temperatures.

Thermal conductivity is to be measured for more than 100 samples of rock from the tunnel; these rocks are chiefly granites, gneisses, and schists. The mean value of conductivity for the first 60 samples is 0.0079 in cal,cm,sec, and °C, at the mean temperature of about 10°C. Combined with the corrected gradients, this mean conductivity gives values of heat flow between 2.0 and 1.6, in units of 10^{-6} cal/cm²/sec, depending upon the assumption as to time of development. These values are significantly higher than the best determinations in lower regions and may be regarded as supporting the hypothesis of crustal thickening in mountain formation.

UNUSUAL STYLOLITES

DANIEL B. BLAKE

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Stylolite seams at near right angles to bedding planes are found in certain limestones along the eastern flanks of the Front Range and Wet Mountains of Colorado, where known thrust faults exist.

Limestones of the Pennsylvanian Fountain, Jurassic Morrison, and Cretaceous Greenhorn and Niobrara (Timpas) formations were studied in detail. The stylolite seams intersect bedding planes at remarkably constant angles whether they occur in undeformed, normally dipping, or strongly

overturned strata. The seams are only roughly parallel, but the axes of the columns show almost no variation in attitude within an exposure.

It is believed that the stylolites formed during the early stages of Laramide orogeny. A system of transverse joints developed in the relatively undisturbed beds of the section, and solution along these joints, combined with continuing stress associated with the thrusting, caused the development of stylolites. The major deformation of the beds, including local overturning, is later than the stylolites.

BAUXITE DEPOSITS OF BABELTHUAP ISLAND, PALAU GROUP*

JOSIAH BRIDGE AND S. S. GOLDICH

U. S. Geological Survey, Washington 25, D. C.; University of Minnesota, Minneapolis, Minn.

The principal bauxite deposits of the Palau group are in the Ngardmau district in the northwestern part of Babelthuap Island. The raw ore consists of bauxite gravel and dark reddish-brown concretionary clay which on washing yields a concentrate of ferruginous bauxite, averaging 51 per cent Al_2O_3. This district might yield 2–3 million metric tons of washed concentrate.

The bauxite formed by weathering of Tertiary volcanic agglomerate and tuff. A typical profile consists of (1) a surface bed of bauxite gravel up to 3 feet thick, averaging 1 foot; (2) a layer of finely divided gibbsite and iron oxides with small concretions, resembling clay in being sticky and plastic, averaging 6–8 inches; (3) dark reddish-brown concretionary laterite grading to clay, averaging 6 feet; (4) variegated clay with concretions of gibbsite and with iron oxides in the upper part becoming less abundant with depth, thickness variable, maximum probably 40 feet; (5) parent andesitic to basaltic volcanic agglomerate and tuff.

The deposits are closely related to the present land surface. They are thickest on the steeper slopes, thinner on divides, while only thin blankets occur in the flatter valley areas. Slopes with good bauxite deposits are characterized by poor bouldery soil, few trees, and a heavy growth of fern.

The Ngardmau deposits were developed by the Japanese South Seas Aluminum Mining Company, 1938–1944. The raw ore was washed, and 369,227 metric tons of washed concentrate was shipped to Japan. Mine and plant installations were badly damaged by American bombing operations in 1944.

FAULT PATTERNS AND FAULT MOVEMENTS

WALTER H. BUCHER

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In 1947 the thesis was presented that, at any given point in a body undergoing deformation, fractures can come into being in three, and only three, positions with reference to the axes of greatest and least strain at that point: (1) normal to the axis of greatest elongation ("tension fractures"); (2) oblique to it, forming an angle of approximately 60 degrees with it ("oblique shear fractures"); (3) under special conditions and limited to rotational strain, parallel with the direction of greatest elongation ("axial plane fractures", not discussed).

As deformation proceeds, some of these initial fractures ("joints") turn into faults or become incorporated in a larger, growing fault zone. The transformation of initial fractures into faults is here traced by comparing laboratory experiments with corresponding typical geological fault systems, such as: (1) horst and graben structure of southeastern Oregon (compression or tension?); (2) localized thrusts in Rocky Mountain ranges (relation of normal to reverse faults); (3) conjugate

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faults of Elk Basin oil dome (change of angle with progressive deformation); (4) tear faults of Rocky Mountain region; and (5) cross faults of typical folded belt, such as the Lower Rhenish coal basin (dominant horizontal or vertical movement?).

These examples show that the mechanical understanding of faulting involves two major elements: the overall "initial strain" that exists in the surface of the body undergoing deformation and is responsible for the "initial fracture pattern"; and the "subsequent deformation" that takes its own course in the spaces between the fractures.

CHARACTERISTICS OF THE LOWER PART OF THE MCLEANSBORO GROUP IN SOUTHERN ILLINOIS*

GILBERT H. CADY

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Because of extensive core drilling by coal companies in the southern part of Illinois it is now possible to compile a more complete generalized section of the lower approximately 700 feet of the McLeansboro group than that supplied by the description of the Delafield core from Hamilton County in 1909. The strata involved extend from the base of the group to the Millersville limestone and include at least 17 coal beds. Strata are arranged in characteristic cyclical order, the cyclical sequence consisting of 14 varieties of sediments including coal and underclay. Also there are noncyclical variegated shales at characteristic positions. The cyclical sequences seem to occur in two phases, a limestone and sandstone phase, so that the complete composite sequence rarely if ever appears. Special consideration is given to the underclay siltstones, the limestone-black shale association, the gray "roof" shale, and the variegated shales.

SUPERPOSED STREAMS OF THE ATLANTIC AND EAST GULF SLOPE

CHARLES W. CARLSTON

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Douglas Johnson's classic theory of regional superposition was applied to Atlantic slope drainage of the northern and central Appalachians and New England. The present study involves extension of the zone of superposed streams southward along the Atlantic slope from the Potomac River to Georgia and westward along the East Gulf slope to western Alabama. Some revision of Johnson's studies northeast of the Potomac River is also necessary.

Throughout a distance of 75 to 125 miles inland from the present inner edge of the coastal plain, from Alabama to New Jersey, the larger rivers show the same pinnate pattern in the oldland that they have in the coastal plain. Their direction of flow across the oldland is the same as in crossing the coastal plain, and their direction of flow in the oldland varies in perfect response to changes in direction of dip of the coastal-plain beds throughout their curving band of outcrop. The pinnate pattern has been considerably altered in the major rivers crossing the folded Appalachians northeast of the Potomac River, but it is still recognizable.

In New England there is evidence of stream superposition to only 75 miles inland from the southern coast line. The general direction of flow of superposed streams varies from southeastward west of the Connecticut Valley to southward east of the Connecticut, following the slope of the Fall Zone peneplain.

Superposition was from coastal-plain sediments that may have been preponderantly continental rather than the strictly marine deposits proposed by Johnson. Except for the Rappahannock, York,

* Presented with the consent of the Chief, Illinois State Geological Survey.

and lower James rivers, which were apparently superposed from Miocene beds, there is no evidence against the hypothesis that superposition was from Cretaceous beds.

EVIDENCE FOR PLEISTOCENE MAN IN AN ALLUVIAL FAN AT LA JOLLA, CALIFORNIA

GEORGE F. CARTER

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Study of a truncated fan just south of the Scripps Institution of Oceanography at La Jolla, California, has revealed a sequence of alluviations, erosions, and soil profiles. The fan accumulated at a time of lower sea level than the present at the foot of the cliffed 300-foot Kearny Mesa on a half-mile-wide platform which is terminated seaward by the head of the La Jolla submarine canyons. The fan is now being rapidly destroyed by wave attack. This is correlated with a modern high sea level and the formation of a deep gully in the fan. The present fan surface is marked by a soil profile characterized by accumulation of clay in the alluvial horizon. Similar buried soil profiles, each associated with a period of gullying, are therefore interpreted as being the result of similar conditions. The critical limit for wave attack seems to be fixed by the upper edge of the La Jolla submarine canyons. When sea level dropped below this limit, it is thought the fan alluviated. When sea level rose above this limit it is thought that the fan was truncated and gullied. Because the fan was built at a time of lower sea level and because the soil profiles indicate both the passage of long periods of time and moister climates than the present, the feature is thought to be of Wisconsin glacial age. The presence of hearths, artifacts, and food shell beneath the soil profiles is of considerable interest because of the implied Pleistocene age of man at La Jolla.

ORDOVICIAN "DINOSAUR-LEATHER" MARKINGS (EXHIBIT)

GEORGE HALCOTT CHADWICK

Catskill, N. Y.

Photographs will be exhibited of astounding current marks covering a space 2 by 10 yards on the under surface of vertically upturned Normanskill graywacke grit and shale beds (Austin's Glen member, approximately Black River age) along the west side of U. S. highway 9-W 3 miles north of West Coxsackie (N. Y.) traffic light.

The purpose is to direct attention to a phenomenon of most unusual character, likely soon to be destroyed by weathering, in the hope that its mode of formation may be explained or at least some reasonable theories suggested.

The pattern consists of a repetition of units each about 1½ by 3 feet in size, and each containing in overall similarity but not perfect duplication 100 or so minor elements that make the whole suggestive of reptilian skin on a gigantic scale. There is, however, no indication of organic origin given in these or in totally different markings on slightly different bedding planes in the same road cut, all of which need explanation.

PENEPLAINS IN MAINE

GEORGE HALCOTT CHADWICK

Catskill, N. Y.

To provoke discussion it is asserted that a peneplain topping the White Mountains (Goldthwait), and Katahdin and Cadillac passes under the Gulf of Maine at a slope connecting with the base of

the Potomac Cretaceous in George's Bank (Stetson and others) and is therefore (post-) Jurassic; that in Maine the New England Upland, sloping under water at the seashore, has to go underneath the later Cretaceous (Mattawan, Navarro equivalents) in George's Bank and must do so also on Long Island, therefore is originally of (post-)Raritan age; that it was buried beneath upper Cretaceous and perhaps Tertiary sediments as far inland probably as the Katahdin bathylith, then tilted in late Cenozoic time and resurrected by recession of a cuesta inface; that the presence of this inface produced at an early stage of recession the cross valley (stream diversions along U. S. Highway 2) submarginal to (Toppan's) Moosehead Plateau and at length the subsequently glacially perfected Gulf of Maine (Johnson, Shepard); that the dissection and terracing (Barrell, Perkins) of the reborn Upland was chiefly Pleistocene and in Maine probably fluvial work not corrrelatable with strata in the Banks because the Great Vale intervened; that the rate of tilt of all peneplains declines greatly from New Jersey northeastward to approximate termination in the Gulf of Saint Lawrence; that a remarkably prolonged stillstand at base level, not an uplift, caused the absence of sedimentary record even from the continental slope throughout Eocene into Miocene time.

REMAINS OF A GABBRO-GRANITE TRANSITION IN NORFOLK COUNTY, MASS.

FELIX CHAYES

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In a gradational transition specimens from the actual transition zone ought to be characteristically intermediate in composition. Compatibility with a "rectangular" or "equal-frequency" parent distribution in the range of intermediate composition is suggested as a minimum criterion of gradation, and the statistical device of a one-sided chi-square test is proposed as a means of testing this compatibility.

The test is applied to a suite of specimens taken from a "gabbrodiorite"-"granodiorite" contact zone well exposed along route 128 in the townships of Dedham and Westwood, Norfolk Co., Mass.

These rocks are all extensively altered, but the alteration seems to have had little effect on the distribution of quartz. The quartz distribution is clearly incompatible with the proposed definition of gradation, rocks of intermediate quartz content being very scarce. It is concluded that this contact offers no evidence of an original gradation from gabbro to granite.

RECENT DEVELOPMENTS IN THE STUDY OF THE PLEISTOCENE OF NEBRASKA

G. E. CONDRA

Nebraska Geological Survey, University of Nebraska, Lincoln, Nebr.

Much new information concerning the Pleistocene of Nebraska has resulted from recent surface and subsurface studies in part actuated by more intensive studies of ground-water resources. Moreover co-operative investigations with bordering States have refined the regional knowledge of the Pleistocene to the extent that more precise correlations can now be made in Nebraska.

The occurrence of Nebraskan and Kansan till in eastern Nebraska has been known for some time, but it has now been proved definitely that Iowan till occurs in a relatively large area in Knox and Cedar counties of northeastern Nebraska, that the Iowan is more extensively represented in southeastern South Dakota and northwestern Iowa than previously supposed, and that glaciation probably correlative to Tazewell reached down across southeastern South Dakota almost to the Nebraska line. Outwash spillways from the Iowan and Tazewell glaciations can be traced southward into eastern Nebraska thus assisting in a more exact correlation of the post-Kansan alluvial and loessal deposits. These correlations aid greatly in dating the terrace deposits of the State. Profile test

drilling is rapidly establishing the relations of the attendant alluvial and loessal deposits of central and western Nebraska to the Nebraskan and later till sheets, and it is believed that a western extension of these studies will permit close correlations with the mountain glaciations west and northwest of Nebraska.

SOME ASPECTS OF THE GEOLOGY AND STRATIGRAPHY OF THE MONONGAHELA AND DUNKARD (PERMIAN) ROCKS OF SOUTHEASTERN OHIO

AUREAL T. CROSS

University of Cincinnati, Cincinnati, Ohio

Over 400 geologic sections in Monroe and eastern Washington counties, Ohio, are graphically summarized in the 683-foot section along Bares Run, near Hannibal, Ohio. The upper 112 feet of the Monongahela series beginning just above the Benwood limestone, the entire Washington formation (230 feet thick), and 341 feet of Greene formation in that section are reviewed with illustrations. Supplementary data for horizons above and below are drawn from near-by exposures to give a composite geologic section about 1000 feet thick from the Pittsburgh coal up to the Gilmore beds.

The key horizons are the Pittsburgh, Benwood, Arnoldsburg, Elm Grove, and Ninevah limestones, an unusual siltstone in the Arnoldsburg horizon, and several coal seams having characteristic lithology, the most important of which are Uniontown, in the west, and Washington, in the east. The most reliable information for interarea correlation is drawn from the establishment of intervals between persistent coaly horizons, some of which are locally or regionally thick coals, whereas others are usually represented by a fraction of an inch of plastic, carbonaceous shale or rarely as much as an inch of blocky coal. Eleven such horizons are recognized from the Monongahela, 10 from the Washington, and 16 are persistent in the Greene. Their positions may be regularly predicted for each exposure. Tentative names are attached to most of these beds pending publication of the final report on the area by the Geological Survey of Ohio. Sandstones are unreliable units for mapping here, due to rapid lateral changes of lithology and abrupt major changes in thickness.

COAL ORIGIN AND NATURAL HISTORY—SUGGESTED RESEARCH

E. C. DAPPLES

(Report of Sub-Committee on Coal Research, SEG)

Northwestern University, Evanston, Ill.

Coal origin is examined from the viewpoint of tectonic control of lithologic associations and the environment of deposition. The accumulated data on coal-sequence associations indicate that coal deposition is the response to more limited range of physical conditions than has been postulated. Analysis of the limiting conditions suggests further investigation of the following as important in coal accumulation: (1) case histories of coal accumulation in zones of mildly unstable shelves and intracratonic basins; (2) the relation between coal types and the associated noncarbonaceous lithologies; and (3) the effect of burial rates on coalification.

LITHIUM-BEARING PEGMATITES IN NORTHERN QUEBEC

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Lithium minerals, especially spodumene, are typical of many of the pegmatites along the margins of a granitic stock in LaCorne Township, north of Val D'Or, Quebec. Recent diamond drilling has shown some interesting features in the structure and composition of these dikes.

The majority of the dikes strike nearly parallel to the nearest part of the granite contact and dip toward the center of the stock. They occur both within the granite and just outside it in basic lavas or sediments.

The unusual feature of their composition is the uniformity in texture and average percentage of the spodumene in individual dikes. One series of such dikes on the north side of the stock shows an average spodumene content of about 25 per cent. The crystals are arranged in a parallel pattern normal to the walls and are accompanied by feldspars, quartz, and minor amounts of beryl and tantalite. The texture of the more consistent dikes is finer than is usually seen in pegmatites. These finer-grained, uniform dikes are usually close to the granite contact, while those closer to the center of the stock are more variable in texture and spodumene content and contain more beryl.

No evidence has been seen that the present minerals were formed by replacement of earlier minerals in the dikes.

TOPOGRAPHY AND SEDIMENTS OF THE BERING AND CHUKCHI SEAS

R. S. DIETZ, A. J. CARSOLA, AND E. C. LAFOND

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During the summer of 1947, an oceanographic survey of a portion of the Bering and Chukchi Sea shelves was conducted from the USS NEREUS during which considerable information was obtained regarding sea-floor processes, deposits, and topography.

A sediment map was constructed from the grab samples, cores, and bottom photos. Also, the diatoms, the Foraminifera, the bacteria, and the mineral content were investigated. The sediments are largely clastic, having a low content of carbonates, organic matter, and authigenic minerals. They show remarkable uniformity over large areas. In the Chukchi Sea ice-rafted detritus is quantitatively important.

Depth profiles obtained with an echo sounder show the shelves to be nonglaciated. They are shallow, smooth, of low gradient (typically less than 1 foot per mile), and devoid of even minor irregularities. The Bering Sea shelf is bounded on the south by a steep (23-degree) continental slope which has the appearance of a structural feature unmodified by sedimentation.

The sea-floor environment of the Bering and Chukchi Sea shelves appears to resemble closely that of the epicontinental cold seas of the past.

LIQUID INCLUSIONS IN HALITE AS A GUIDE TO GEOLOGIC THERMOMETRY

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The gaseous phase of primary liquid inclusions in sedimentary Kansas halite vanishes between 70°C and 100°C. This temperature probably is much above those temperatures generally prevailing in the Permian seas at the time of salt deposition. It is suggested that, if the liquid-inclusion method is a valid guide to geologic thermometry, the method gives, after pertinent pressure corrections, only the temperature of the solution at the surface of the crystallizing material, and that the general temperature of the mineralizing solutions may be much below that indicated by the liquid inclusions.

GIANT FAUNA IN THE SELMA CHALK

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The significance of dwarf invertebrate faunas has been the subject of discussion in numerous papers and symposia. Only rarely has the opposite, giant faunas, been observed. A fauna of giant

size has been found near the base of the Selma Chalk at Plymouth Bluff, Mississippi. This locality on the Tombigbee River has been a famous collecting spot for Eutaw and Selma Chalk fossils for almost a century. Recently a cephalopod over 5 feet in diameter and a rudistid more than 18 inches in length were found associated with the well-known oyster, *Exogyra ponderosa*, and the bones of several trachodon dinosaurs. Environmental conditions for such giant growth are suggested.

CORALS OF THE DEVONIAN TRAVERSE GROUP OF MICHIGAN; PART I: SPONGOPHYLLUM

G. M. EHLERS AND E. C. STUMM

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This paper is the first of a series of papers devoted to the study of the corals of the Traverse group. The genus *Spongophyllum*, heretofore unrecorded from the Devonian rocks of Michigan, is represented by two new species. One of these is from the Rockport Quarry limestone; the other is from the Potter Farm formation. The latter is very similar to an undescribed species from the Callaway limestone of Missouri.

GEOLOGY OF THE BARRILLA MOUNTAINS, TRANS-PECOS TEXAS

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University of Texas, Austin, Texas

The Barrilla Mountains, which constitute the northeastern part of the Davis Mountains of Trans-Pecos Texas, are composed of volcanic materials of Tertiary age. Five tuffs and five lava flows are described; these are 1500 feet thick and occur throughout the Barrilla Mountains with remarkable persistency in thickness and lithology. The upper surfaces of the tuffs and lavas show little or no erosion. The lavas are chiefly acidic and soda rich.

The volcanic succession is underlain by a Tertiary sandstone, which is underlain by marine formations of late Cretaceous age. The Cretaceous formations were slightly deformed by the Laramide revolution and subsequently beveled to a surface of low relief. This erosion surface is everywhere covered by the sandstone, which was deposited by coalescing streams. The sandstone contains chert and quartzite pebbles that are rounded almost to sphericity.

Following the extrusion of the youngest lava flow, broad folds and normal faults affected the area of the Barrilla Mountains and the northeastern part of the Davis Mountains.

WALCHIA: ANATOMY OF BRANCH AND LEAF

MAXIM K. ELIAS

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Anatomically well preserved leafy twig of *Walchia*, the ancestral conifer, was recently discovered in the Pennsylvanian of Kansas. Previously only the anatomy of a fragmentary innermost portion of wood attached to petrified pith was described (Weiss, 1872), while no anatomically preserved leaves were known. However, cuticle of leaf compressions was described by Florin (1938–1939).

The specimen represents 4-inch-long basal part of plagiotropic branch with dorso-ventrally compressed oval cross section 1 centimeter long. Medulla of the pit wedges into the ring of 13 vascular bundles (some of them double) located within the woody cylinder at its inner edge. Numerous rays, mostly biseriate, usually 2 to 6 rows deep, traverse 1½-mm.-thick wood. Helical primary xylem is succeeded centrifugally only by secondary tracheae whose radial walls bear double rows of alternate hexagonal bordered pith.

Leaves flattened dorso-ventrally, lanceolate, expanded into basal cushions distributed with $\frac{1}{3}$ spiral phyllotaxis. Single vein is much broadened laterally, consisting of numerous narrow elements, surrounded by irregular zone of larger transfusion cells, which in turn is surrounded by wider zone of still larger chlorophyllous cells. Polysade layer only on upper side of leaf, under several cells deep layer of narrow hypodermal fibers, quite continuous around the leaf. Locally preserved cuticle with stomata and numerous circular openings, which Florin interprets as bases of detached hair.

Walchia combines features of various living conifers, its wood resembling that of Araucariaceae and the leaves those of Podocarpaceae and sterile bracts of Pinaceae.

STEREOPHOTOGRAPHY AS A TOOL OF THE PALEONTOLOGIST

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Stereophotography can contribute much to the field of paleontologic illustration. The techniques involved in producing satisfactory results are easily mastered, and the photographic equipment necessary is of simple design. The resulting stereograms can be viewed either with a pocket stereoscope or with the unaided eye. Stereophotography should be particularly useful in the illustration of moderately small specimens with prominent three-dimensional form or of structural details hidden in concavities where profile views cannot be obtained.

The only significant drawback to the extensive use of stereophotography for publication is the additional plate space required. This can be kept at a minimum by consideration of these factors: (1) Not all views warrant stereophotography; careful selection is needed. (2) In some instances stereophotography might permit the elimination of views from other angles. (3) Careful planning of plate layout and combination of stereograms with single photos would make most profitable use of available space.

By presenting an accurate three-dimensional image stereophotography has important potential uses other than for publication: (1) building up a file set of stereograms which would substitute satisfactorily for repeated study of type material, (2) creating a permanent record of specimens after coating with a whitening agent to reveal details of structure and ornamentation, and (3) as a teaching aid permitting simultaneous examination by large numbers of students of pre-selected and oriented specimens and details of specimens where microscopes are few.

ATLANTIC CRUISE 152 TO THE MID-ATLANTIC RIDGE

MAURICE EWING

Columbia University, New York, N. Y.

During a 2 months expedition, over 7600 miles of continuous fathometric recording, 731 seismic reflection stations, 3 seismic refraction profiles, and 10 isolated refraction tests, 32 ocean-bottom photographic stations, 12 keep sea cores—mostly 30 feet in length—and several interesting hauls with the rock dredge and Blake trawl were made.

The results of this work confirmed and extended those of the previous season.

PRE-CAMBRIAN FOSSIL TRAILS FROM THE AJIBIK QUARTZITE IN MICHIGAN

HENRY FAUL

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Sinuous markings have been found on a ripple-marked bedding surface in the Ajibik quartzite

near the Ropes gold mine north of the Marquette iron range in Michigan. The formation is a hard white quartzite, steeply dipping to the south, and is generally accepted as Huronian in age. The trails cross ripple marks in gently curving wavy lines, reminiscent of the paths left by small invertebrates in wet sand.

BURIED SURFACE OF THE CENTRAL AMARILLO MOUNTAINS, TEXAS

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Recent work involving critical re-examination of cuttings from selected wells in the area of the central Amarillo Mountains, Texas, has furnished data regarding the topography and lithologic nature of this portion of the buried range.

A map showing the nature of this buried surface and some structural inferences is shown.

TECHNIQUES IN PALEOECOLOGICAL STUDY OF TERTIARY FORAMINIFERA

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Several lithologically well-defined Tertiary formations in Texas are suitable for detailed paleoecological study of the Foraminifera. A research program of this type requires special techniques in all phases of the study from sampling the outcrop to presentation of the assembled sedimentational and micropaleontological data. Field work at the outcrop requires detailed examination of the exposure, sketched profile of the exposure, precise measurement of the exposed section, detailed description of every lithologic unit in the section, and careful sampling of every unit in the exposed section. Detailed descriptions of a hand sample of each bed are recorded in the laboratory prior to additional study of that sample.

Preparation of individual samples for study necessitates washing by double decantation and concentration of microfossils by electromagnetic and carbon tetrachloride separation. The washed concentrates are described in qualitative detail as to minerals, grade size, and organic content during careful microscopic examination. Details of indurated beds are described from thin sections. The Foraminifera are carefully picked according to relative abundance from sieved fractions of every concentrate, thus ontogenetic study can be made for each species in every sample. The stratigraphic distribution of the fauna at each exposure is presented in chart form showing relative abundance of each species, lithology and thickness of the corresponding sampled beds, and is accompanied by a chart showing the details of the sediments of each bed. Lateral distribution of the fauna and sediments is illustrated in chart form by combining several stratigraphic-distribution charts and by showing the relative abundance of a few important species, lithology, and thickness of the respective sampled beds.

PREGLACIAL DRAINAGE OF SOUTH DAKOTA*

RICHARD FOSTER FLINT

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The south-flowing Missouri River in South Dakota was stated by Todd in 1914 to have originated along the margin of an ice sheet, which advanced from the northeast and blocked a preglacial east-flowing drainage system.

* Published by permission of the Director, U. S. Geological Survey.

Todd's basic concept is believed correct. However, the preglacial stream pattern is believed to differ from Todd's reconstruction. The evidence consists chiefly of (1) major valleys east of the Missouri, now partly filled with drift; (2) varying character of upland slopes along the Missouri; (3) configuration of bedrock surface beneath the drift.

After crossing the site of the present Missouri, the principal preglacial streams probably followed these routes:

(1) White River continued east across present James River, thence southeast via Vermillion River.

(2) Bad River continued east via Medicine Knoll Creek and Ree Valley, thence obliquely across James River to Vermillion River.

(3) Cheyenne and Moreau rivers joined, flowed east to the James, thence northward to Red River.

(4) Grand River and two streams north of it joined and continued southeast to join the preglacial Cheyenne.

Hence, preglacially, the Arctic Sea—Gulf of Mexico divide crossed the present James near Redfield, S. D., whereas today it lies nearly 200 miles farther north.

Nearly every segment of the present Missouri is a part of some preglacial valley, however small. Thus the Missouri was localized by glacier margins only indirectly. As an integrated river it is glacial, but its course is a patchwork of preglacial routes. In this respect it is far more like the Ohio than was suspected earlier.

Preglacial does not necessarily mean pre-Pleistocene, and not all the diversions necessarily occurred during a single glacial age.

FAULTING ON THE NORTHEASTERN FLANK OF THE OZARKS

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One of the structures forming the eastern boundary of the Ozark fault block is a newly described fault zone trending approximately N. 10° E. in the vicinity of St. Louis, Missouri. This zone is followed by the Mississippi River from where its course is determined by the Cap-au-gras fault just north of St. Louis to where the zone intercepts the Crystal City fault south of St. Louis. The course of the Mississippi is in a large measure controlled by the Cap-au-gras fault system, then by this zone, and then by the Crystal City and Sainte Genevieve fault systems. This apparently explains the anomaly of the Mississippi cutting across the eastern flank of a structural and topographic high instead of flowing in the low to the eastward.

CONTRIBUTION TO THE STUDY OF ARKANSAS BAUXITE

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The use of a combination of techniques comprising chemical, differential thermal, x-ray, spectrographic, optical (thin and polished section), and staining methods on a drill core of Arkansas bauxite indicated that the major proportion of the alumina has been either reworked from the original colloids or introduced. Kaolinite developed at a late stage through the introduction or fixation of silica accompanying basic carbonate (siderite) solutions. Ions of Ti, Zr, and U occur adsorbed on the hydroxides.

The sequence of events that led to the development of the bauxite is believed to be as follows:

1. The nepheline and orthoclase in the syenite, on being subjected to weathering processes, were hydrated and ionized:

$$\left.\begin{matrix}KAlSi_3O_8\\(Na,K)AlSiO_4\end{matrix}\right\} \longrightarrow (AlSi\cdots OH)^{-}\cdot nR^{++}$$

The R^{++} was exchanged by $2H^{+}$ on contact with "acid" oxidizing solutions or clays giving rise to more or less solid aluminosilic acid.

Sulfuric acid, produced from the oxidation of iron sulfide resulting from the sulfate bacteria common in clays, operates on the clay colloids giving rise to hydrated aluminum sulfate and colloidal silica. The weak acidity of the solution stabilizes the colloidal silica, and hence it is easily removed whereas the aluminum salt is hydrolized to give aluminum hydroxide (which remains) and sulfuric acid to continue the process.

Further weathering and the introduction of basic solutions fix the silica giving rise to the kaolinite now found between the bauxite and syenite.

The gibbsite did not weather from the kaolinite; the nature of the solutions attacking the syenite determined which mineral would develop.

TRILOBITE FAUNA OF THE HONEY CREEK FORMATION

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The Honey Creek formation contains an interesting and diagnostic trilobite fauna of lower Franconian age. Twenty-three genera and 30 species of trilobites including 9 new genera and 17 new species are described. Relative ranges and zonation of the genera are shown. The correlation of the Honey Creek formation with other equivalent Upper Cambrian units is discussed.

DIASTEMS IN THE PECAN GAP CHALK (UPPER CRETACEOUS, TAYLOR GROUP) OF TRAVIS COUNTY, TEXAS

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Foraminifera encrusting on mollusk casts demonstrate the presence of diastems in the Pecan Gap chalk (Upper Cretaceous, Taylor group) near Austin, Texas. Three diastems have been traced in this exposure, the upper two separated by a sedimentary wedge and merging within the outcrop. It is stressed that these intraformational hiatuses must be taken into account in attempting detailed microfaunal zonation.

RETGERSITE, $NiSO_4 \cdot 6H_2O$, A NEW MINERAL

CLIFFORD FRONDEL AND CHARLES PALACHE

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The well-known artificial compound, tetragonal $NiSO_4 \cdot 6H_2O$, is described from five natural occurrences: with morenosite and minasragrite at Minasragra, Peru; with annabergite at Cottonwood Canyon, Churchill Co., Nevada,—at Lobenstein, Thuringia,—and at Lichtenberg, Bayreuth, Bavaria; and with ferroan chalcanthite at the Gap Nickel Mine, Lancaster Co., Pennsylvania. Tetragonal trapezohedral, with $a:c = 1:2.7038$ (artificial; Scacchi,1863); $a_o = 6.765$ kX, $c_o = 18.20$, $a_o:c_o = 1:2.690$ (Minasragra). Uniaxial negative, with nO = 1.510, nE = 1.486 (natural). Crystals from Minasragra are short prismatic [001] with {001}, {110}, {011}, {012}; also found as fibrous

crusts and veinlets. Color blue green. G 2.04 (Nevada). Cleavage {001} perfect, {110} in traces. Analysis gave :NiO 26.87, MgO 0.65, FeO 0.63, SO_3 30.32, H_2O [41.53], total [100.00] (Nevada). The name retgersite is proposed for the mineral in honor of J. W. Retgers (1856–1896), Dutch chemical crystallographer.

Only 4 of the 23 reported natural occurrences of morenosite, orthorhombic $NiSO_4 \cdot 7H_2O$, can be said definitely to be of that species.

USE OF FOSSIL SOILS IN KANSAS PLEISTOCENE STRATIGRAPHY

JOHN C. FRYE

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A buried soil profile constitutes diagnostic field evidence of an unconformity and so is of value in stratigraphic classification and correlation. Pleistocene fossil soils have long been used in the Mississippi valley region, and during the past decade have been studied extensively in Nebraska, particularly in association with fossil vertebrates. A succession of fossil soils has been recognized in the Kansas Pleistocene—at the top of Nebraskan and Kansan glacial tills, the upper silty member of the Meade formation, and the Loveland and Peoria members of the Sanborn formation. The Loveland soil and the Brady soil (at the top of the Peoria member) have been studied in northern Kansas from the Missouri River approximately 400 miles west. Their character changes markedly from east to west in response to climatic differences. The Brady soil in northeastern Kansas is leached as much as 15 to 20 feet, and locally the caliche zone contains nodules more than 2 inches in diameter. In north-central Kansas this soil is leached 2 to 3 feet, and caliche nodules rarely exceed ½ inch in diameter. In northwestern Kansas the top soil—although dark gray with organic matter—retains some calcium carbonate, and caliche occurs in small pellets 1–2 feet below the soil surface. The Loveland soil reflects a longer period of weathering under more subdued topographic conditions. In north-central Kansas it is leached approximately twice as deep as the Brady soil and is generally characterized by a more prominent caliche zone.

BASALTIC FAN JOINTING INDUCED BY AQUEOUS CHILLING

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At Rock Island, Washington, the eastern escarpment of the Columbia River Valley exposes a thick basaltic flow with marked "ball and socket" columnar jointing. Locally this flow shows the development of well-defined columnar fan jointing radiating from vertical cracks which formed cooling surfaces. Laterally the fans grade rapidly from fine to coarse horizontal columns which have been confused with dikes. An alteration of smooth and rough transverse surfaces on the joint prisms of the fans as well as on the vertical columns of the flow also suggests exceptional acceleration of chilling. This chilling is considered to have been induced by the flooding of the surface of the flow with water, the presence of which is indicated by overlying palagonitic breccia formed by the aqueous granulation of a subsequent flow.

HYDROTHERMAL SYNTHESIS OF ENARGITE AND TENNANTITE

R. V. GAINES

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Crystallized enargite (Cu_3AsS_4) and tennantite ($Cu_{12}AsS_3$) have been synthesized hydrothermally at temperatures in the range 350°–430°C. Arsenolite, orpiment, and several unidentified substances

were obtained in minor amounts in some instances concomitantly with enargite or tennantite. The reactants, which variously included Cu, CuCl, $CuCl_2$, CuS, As_2S_3, As_2O_5, S and Na_2S, together with water, were sealed in Vycor tubes and heated within steel pressure bombs of conventional design. The laboratory conditions favorable to the formation of enargite and tennantite were explored by variation of temperature, composition, and pH of the solutions.

MOVEMENT OF DISSOLVED MATERIALS THROUGH ROCKS

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One type of transfer of dissolved materials through rocks is that in which the rock is first saturated with solvent (water), and the movement of materials through the rock takes place by diffusion of ions or molecules through the stationary solvent in the rock pores. The amount of material which moves through a unit cross-sectional area of unit length is determined chiefly by the concentration gradient, the temperature, the diffusion coefficient of the solute used, and the effective or connected pore area of the rock used. Measurements were made of the amount of transfer of potassium chloride through several limestones. Neither the permeability nor the porosity (as determined by saturating the rock sample with water) was a good indicator of the amount of material expected to diffuse through the rock. Apparently the amount of material passing through the rock is independent of pore size but is a good measure of the area of pores forming continuous channels through the rock in the direction measured. The work indicated that below 100° C. transport by ionic or molecular diffusion through a fixed solvent is an effective geologic process only over distances measured in a few inches or at most a few feet.

APPLICATION OF THE CONTACT-PRINT TECHNIQUE*

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The contact-print technique was applied to ore from the Salt Chuck copper-palladium mine, Prince of Wales Island, Alaska, to determine where the palladium was localized and to distinguish between the copper sulphide minerals. Palladium was localized with the specific test reagent, p-Dimethylamino-benzalrhodanine.

GEOLOGY OF THE GARRISON DAM, NORTH DAKOTA

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Garrison Dam is located on the Missouri River in west-central North Dakota. Missouri River has trenched itself in the Fort Union sediments of the Missouri Plateau 200 feet at the site, and the valley is 2 miles wide. Valley fill consists of over 100 feet of alluvial sands, clays, and clayey glacial till. The dam is to be constructed primarily of rolled Fort Union sediments, excavated from the chute-type spillway located on the east abutment and the outlet-works tunnel portals in the west abutment. There will be eight tunnels, 30 feet in diameter and 1200 feet long.

Modern methods of subsurface sampling have made available foundation materials for laboratory testing. The application of soil-mechanics techniques has demonstrated the feasibility of placing

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the earth structure on the valley-fill materials and concrete structures on Fort Union materials. High slopes developed under natural conditions have been measured and used to check theoretically designed slopes. Investigations of underground lignite mines were made as a prelude to test tunnel design. Pumping-out tests made in lignite beds determined rate of recharge. Grouting tests demonstrated the feasibility of cutting off the flow of water in lignite horizons. Methods of storing subbituminous coals will be applied to the storage of over 4,000,000 cubic yards of lignite. A test tunnel is being built which will be used as a full-scale model in which observations and measurements are being made on Fort Union clays as a guide to ultimate tunnel design.

ORIGIN AND DEVELOPMENT OF ALUMINOUS LATERITE AND BAUXITE*

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Aluminous laterite and bauxite form directly by weathering of igneous rocks above the water table in regions where climate, topography, rock types, and possibly other factors are favorable. Below the water table clay minerals are favored as the end product of weathering. For this reason bauxite deposits commonly grade downward to clay which in the earlier literature has been referred to as a "transitional" clay between the bauxite and the parent rock.

The clay layer is a normal product in tropical regions where weathering has progressed deep enough and where physical conditions permit establishment of a permanent water table. In this zone kaolin minerals—endellite, halloysite, and kaolinite—develop either by direct crystallization or by silication of aluminum hydroxide.

The establishment of a permanent water table in a deep weathering profile marks the end of the cycle of laterization and a physical-chemical change from conditions favoring gibbsite development to those favoring clay minerals. The physical change is chiefly one of drainage, from free and easy water movement to sluggish and incompetent circulation. The change in chemical equilibrium probably is largely one of pH. The cycle of laterization may be accompanied by a change in vegetation, but it is not clear whether this is simply a consequence of the cycle or in part a controlling factor.

In the late stage of weathering secondary processes are initiated which bring about a redistribution of the constituents in both laterite and in the underlying clay.

SOME ASPECTS OF THE SYSTEM $NaAlSiO_4$-$CaO \cdot Al_2O_3$

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The thermal-equilibrium relationships in the system $NaAlSiO_4$-$CaO \cdot Al_2O_3$ have been investigated. Complex relations exist at temperatures above the carnegieite-nepheline inversion range, the system at these temperatures being quaternary in nature. At lower temperatures, in the stability field of nepheline, simplification to a binary system is observed over a considerable portion of the system, due to the ability of nepheline to take up somewhat over 60 per cent $CaO \cdot Al_2O_3$ in solid solution. The complexity at higher temperatures is due to the inability of carnegieite to include more than a small amount of $CaO \cdot Al_2O_3$ in its structure, and to the intrusion of fields of β-Al_2O_3, corundum, and $CaO \cdot 2Al_2O_3$.

Soda volatilization is significant in the system, and apparently the rate is increased as lime is added. As soda is lost, β-Al_2O_3 or corundum tends to crystallize. The possibility of this effect being related to the corundum present in some alkaline rocks, particularly those associated with limestone, and to soda enrichment (albitization, etc.) of the country rock is discussed.

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RETROGRESSIVE ALTERATION FOLLOWING GRANITIZATION AND RHEOMORPHISM

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At Cornucopia, Oregon, some areas of granitic rock are transected by numerous parallel alteration bands a few feet apart. They range from a fraction of an inch to 2 inches in width and have outer borders of sericitized and kaolinized granodiorite. Quartz is the chief mineral, with some microcline and orthoclase. Were it not for the strong evidence that the granitic rock has been formed by metamorphism rather than consolidated from a magma, these bands would be interpreted as deuteric. The sericitization and kaolinization is indicative of temperature lower than that which obtained during granitization.

Rheomorphic dikes in this region exhibit crystalloblastic macrotextures and pronounced flow structures. Some of these dikes, which are 4 or 5 feet wide and nearly vertical, are horizontally transected by light-colored alteration bands, up to 2 inches in width, several inches apart. These bands pinch out in the wall rock within 2 inches from the dike. They contain a few horizontal veinlets of epidote and chlorite. In a large thin section, it can be seen that the contacts with the unaltered part of the dikes are indistinct and that relict flow structure continues through them. Most of the original mafics of the dike have disappeared, and even some of the plagioclase has been partially epidotized as well as kaolinized. There has been an apparent increase of alkali feldspar and quartz. It seems, therefore, that there is a close analogy in the mode of origin of these alteration bands to deuteric processes in igneous rocks.

SIZE AND SORTING IN SOME TRINIDAD SEDIMENTS

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In sediments from South Trinidad, B.W.I., it has been found that the sorting (phi percentile deviation $PD\phi = \frac{P_{90\phi} - P_{10\phi}}{2}$ may be expressed in terms of the average grain size (phi median, $Md\phi$ by means of linear equations of the form $PD\phi = b\,Md\phi - a$. Association between $Md\phi$ and $PD\phi$ measured by the correlation coefficient gives values of "r" from 0.5913 to 0.7923 on the basis of several sets of (25–84) random samples from different sets of data; tests of significance consistently give $P < 0.01$.

The coefficients "a" and "b" of the linear equations vary only slightly for different sets of data within a restricted area (6 square miles) and over a stratigraphic interval exceeding 5000 feet within the Miocene. These values change materially within similar horizons over a distance of 40–50 miles. Size and sorting factors of Oligocene sediments show similar linear relationships within the restricted range of sizes tested ($Md\phi = 2.5 - 4\phi$).

Deviations from the trends can be attributed to experimental error (flocculation of clay fraction, errors in reading from and smoothing of the cumulative curves) and to changes in sedimentation. One sand body consistently better sorted than predicted from its $Md\phi$ may be an example of local reworking during a tectonically stable period prior to an unconformity. Others showing poorer sorting than predicted by the linear equations may reflect local "tectonic" incidents such as the incorporation of mudflow material from active mud volcanos.

EARLY STAGE OF DIVERGENCE OF TWO TRIASSIC GASTROPOD GENERA

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Two new genera of Triassic gastropods from Central Peru, constituting a subfamily tentatively referred to the Cirridae, are discussed, from both phylogenetic and ontogenetic angles, as an example of an early stage of generic divergence.

PROBABLE AEOLIAN DEPOSITS IN THE BRANDYWINE FORMATION OF THE COASTAL PLAIN OF MARYLAND*

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The present project was begun in 1946 as part of a program of co-operative research between the U. S. Geological Survey and the Bureau of Plant Industry, Soils and Agricultural Engineering, United States Department of Agriculture. Its major purpose is to determine the origin and history of several Coastal Plain soils in the vicinity of Washington, D. C. One phase of the project has been to map in detail the areal geology of the Brandywine 7½-minute quadrangle, the type area of the formation of principal interest. The Brandywine formation in this area consists of a basal gravel member 10–30 feet thick, overlain by 10–15 feet of silt, sandy clay, and sand. The formation underlies about 60 per cent of the quadrangle and forms a gently rolling dissected high plain about 230–260 feet in altitude. At a few places gravel probably made up the entire formation before dissection. Many of the highest points in the quadrangle are occupied by elongate bodies, 2–10 feet thick, composed of well-sorted fine sand resting on gravel, silt, or sandy silt. These bodies have a uniform northwest orientation and are interpreted as dunes. Much of the remaining surface is underlain by thin loesslike silt and sandy silt. The general slope of the Brandywine formation at the type area is about 4–5 feet per mile to the south. The formation is interpreted as the deposit of a large stream or stream system probably formed under periglacial climatic conditions which permitted thin deposits of sand and silt to be formed by the wind on the surface of the flood plain.

GEOLOGY OF THE HARLAN COUNTY DAM, REPUBLICAN RIVER, NEBRASKA

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Harlan County Dam is a rolled-earth structure about 2¼ miles long and 100 feet high, under construction on Republican River, southern Nebraska. The embankment rests on floodplain sands about 35 feet thick, after stripping a few feet of silt, or on about 15 feet of sands covering a wide rock terrace, after stripping about 40 feet of loess and alluvial silt. Trenches filled with compacted silt cut off floodplain and terrace sands under the embankment, to underlying Niobrara chalk. Terrace loess is the principal source of impervious fill, and cutoff and spillway excavations provide sand for pervious sections.

The right abutment is a steep Pierre shale bluff, underlain by Niobrara chalk. Removal of weathered shale requires stripping 10 to 20 feet, and locally more where shale has been down-dropped by faults. The left abutment is covered with thick Pleistocene loess and alluvial silt, over sands,

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with the water table held high in the sands by impervious silt mantling the lower valley side, requiring care to avoid draining ground water into the cutoff excavation.

The concrete spillway is designed especially for stability on the Niobrara chalk of the terrace, which contains many thin bentonitic clay seams and several high-angle faults. Rock suitable for concrete aggregate must come from distances of 300 miles, or more, but riprap stone is available from several local deposits of opal-cemented Tertiary "quartzite". Extensive testing is underway for selection of fine aggregate, as Republican River sands have been suspected of deleterious reactivity in concrete.

STRIATED BOULDERS ON THE MEDICINE BOW MOUNTAINS, WYOMING

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Excellent and definitely striated boulders were discovered during 1934 in section 34, T. 16 N., R. 79 W., 4 miles south of the Snowy Range of the Medicine Bow Mountains. Much older and higher than the Wisconsin terminal moraine, they are on the high divide 10,600 feet altitude separating drainage west into French Creek, a tributary of the North Platte River, and east into Mullen Creek, a tributary of the Laramie River. These striated boulders are beyond and 100 feet or so higher than the Wisconsin moraine, and, moreover, are squarely on the high divide of these mountains. They occur on a smooth grassy and tree-covered hill devoid of the typical hummocky topography common to ordinary glacial debris.

Ice should have filled the tributaries of the Laramie and Platte rivers, in order to have held the ice high upon the divide, and some related glacial debris should occur down these tributaries and even out in the valleys of the master streams if the striated boulders are of Pleistocene age. None has ever been reported.

These facts indicate much greater age for these striae than the Wisconsin, or even than the Kansan. The general geology of the mountain points to possible Eocene age.

PRE-BELTIAN ROCKS NEAR DILLON, MONTANA*

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Three major units of pre-Beltian metamorphic rocks occur near Dillon, Montana. The oldest consists of a series of banded gneisses that are similar to rocks of the Pony Series. Above these lies a group of marbles, schists, and quartzites, about 2 miles thick, belonging to the Cherry Creek Series. Hornblende gneiss, interlayered with these metasediments, represents chiefly metamorphosed mafic sills, for vestiges of earlier contact-metamorphic effects are preserved, and locally the gneisses transect the marbles. Cutting both Pony and Cherry Creek rocks is a batholith of red granite gneiss (Blacktail granite gneiss). Transecting these units are dikes and irregular sheets of pegmatite, diabase, and peridotite, unmetamorphosed and of uncertain age.

NEW EVIDENCE ON THE AGE OF THE RICO FORMATION IN COLORADO AND UTAH†

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The Rico formation was first adequately described and named in 1900 by A. C. Spencer for sediments in the San Juan Mountains, Colorado, that are transitional between the Pennsylvanian

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Hermosa formation, and the overlying red beds of the Cutler formation, of supposed Permian age. Girty determined the first fossils collected from the Rico as Permian with doubt, but on the basis of later and better collections as upper Pennsylvanian, in which age the Rico was classed in the several quadrangle reports on the San Juan Mountains by Whitman Cross and associates.

More recent Geological Survey parties west of the San Juan Mountains, in the Moab and San Juan River regions, Utah, have found fossils in the Rico that were determined again as Permian, in which classification the formation has remained.

A search for Foraminifera in the Rico formation of the San Juan Mountains has resulted in finding a species of *Fusulina* in the Rico that indicates middle, or possibly upper, Des Moines age (Pennsylvanian). *Triticites* sp. from the Rico of the Moab region, Utah, indicates that the Rico of that region is of upper Pennsylvanian age. In summary, the evidence so far found indicates that (1) type Rico is of Des Moines age and (2) the transition facies of the Rico rises in the time scale toward the west and southwest. It is suspected that at least a part of the red beds of the Cutler formation at the type locality is also of Pennsylvanian age.

MOORE COUNTY METEORITE; A FURTHER STUDY WITH COMMENT ON ITS PRIMORDIAL ENVIRONMENT

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The Moore County meteorite in bulk composition resembles a Sudbury norite. The pyroxenes present were initially a single phase, pigeonite. This has undergone a complicated series of changes from which it is deduced that the temperature of the original environment was approximately 1135° C. and that the meteorite left this environment with catastrophic suddenness. Investigation of the fabric of the meteorite indicates a well-developed dimensional orientation of the plagioclase and pyroxene. The plagioclase *b* and *c* crystallographic axes and the pyroxene *c* axis tend to lie in one plane. The fabric is considered to represent primary layering developed by crystal accumulation on the floor of a magma chamber. This crystallization differentiation must have occurred in the original environment. Various lines of evidence suggest that the parent body from which the meteorite came was of the same order of magnitude of size as the Earth.

TECHNIQUES OF COLLECTING MICROVERTEBRATE FOSSILS

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In the past 10 years thousands of invertebrate and vertebrate fossils, many of which were previously unknown to science, have been removed from Pliocene and Pleistocene deposits by sifting or washing the matrix. Channel sands are dried, and sifted through a series of screens of different mesh sizes. Sandy silts, silts, and clays, which contain fossils, are dried. This material is then placed in a water bath which allows the removal of the matrix from the fossils.

This method of collecting has brought to light numerous faunas, which consist dominantly of small forms. Many of the small forms, especially the rodents, have proven to be the best stratigraphic markers known in late Cenozoic deposits. These small forms reveal more facts concerning climatic conditions at the time they lived than the larger and more spectacular vertebrates.

DISTRIBUTION OF ACCESSORY ELEMENTS IN PEGMATITES

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A mathematical theory for the distribution of accessory elements in the minerals of pegmatites is derived. The admittance of accessory elements by crystal lattices, the distribution of accessory elements as a function of the distance from the wallrock-pegmatite contact, and the effect of disturbing factors on the cooling history of a pegmatite are discussed. The theory is illustrated with an artificial example, and suggestions are made relative to its testing by experimental data. It is proposed that such testing will elucidate the mechanism of pegmatite formation.

PLEISTOCENE DEPOSITS OF THE ROSS SEA AND SOUTHEASTERN PACIFIC OCEAN

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Sea-bottom core samples collected by the writer on the U. S. Navy Antarctic Expedition of 1946-1947 are being studied by several specialists. The present report contains a description of the lithologic characteristics of the samples correlated with radioactivity—age determinations made by Wm. D. Urry of the Geophysical Laboratory, Carnegie Institution of Washington. These data indicate that in the Ross Sea, Antarctica, glacial marine deposits were accumulating during most of the Pleistocene, since about 1,100,000 years ago. Two zones interpreted as interglacial deposits appear to coincide with the Yarmouth and Sangaman stages, and the evidence presented indicates that glaciation was contemporaneous in the Northern and Southern hemispheres.

A core sample from 9° S. Lat. in the eastern Pacific contains several alternating layers of Globigerina ooze and red clay in a deposit which apparently represents a span of 990,000 years. The layer of thickest, purest Globigerina ooze occurs at approximately the Yarmouth interglacial stage on the radioactivity time scale. Other tentative correlations are suggested.

FISSILITY AND NONFISSILITY IN SHALES AND MUDSTONES

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An empirical megascopic classification of lutite breaking characteristics is proposed whereby lutites can be described as massive, flaky-fissile, flaggy-fissile, or some combination of these three pure types. Fissility in shales is usually associated with a parallel arrangement of the micaceous clay particles.

Experiments and observations imply that the clay particles attain a parallel orientation by gravity settling or by flocculation and compaction, unless the particles are adsorbed on irregularly shaped sesquioxide or silica particles or grow randomly in a gel. Organic matter greatly increases the tendency toward a parallel arrangement.

If the cementing agent can hold the material together in a large slab, the shale will be flaggy. If the amount or tenacity of the cementing agent is small, the shale will be flaky. Cementing agents other than organic matter tend to hinder cleavage parallel to the flaky clay particles causing a decrease in fissility and an increase in massiveness.

Moderate weathering increases the fissility of a shale. Intense weathering will probably result in a soft massive clay.

In general, the type of fissility or the lack of fissility does not correlate with the size distribution of particles or the kind of clay minerals present in a random collection of lutites.

PALEOZOIC VOLCANIC GEOSYNCLINES AND ISLAND ARCS

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Published data on volcanic flows and coarse fragmental rocks in Paleozoic sequences of North America show such rocks to be practically limited to belts bordering the Pacific from the Aleutians to California, and the Atlantic and Gulf coasts from Newfoundland to northern Mexico; earlier Mesozoic volcanics continue to be restricted to the Pacific belt. The volcanic rocks and associated sediments are in eugeosynclines. Some of the volcanic rocks are subaerial, formed on volcanic islands, whereas others are submarine. Among the sediments, conglomerates include plutonic and sedimentary pebbles, and angular unconformities and intrusive stages interrupt sequences; moreover, some terrigenous sediments in adjoining nonvolcanic or miogeosynclinal belts coarsen toward the volcanic belts. Thus there were tectonic as well as volcanic islands.

Information is insufficient to permit other than qualitative judgment on the proportions of different rocks. Among volcanics, basalts and andesites seem of greater quantity than rhyolites, but the latter are locally prevalent. Belts of ultrabasic intrusions recorded by Hess are in the eugeosynclinal belts. The paleogeography is similar to that of present island arcs of the East Indies and West Indies, and the geology resembles that of the early Paleozoic Welsh geosyncline.

ABSORPTION OF INFRA-RED RADIATION BY CLAY MINERALS

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Absorption of infra-red radiation by clay minerals varies both in intensity and in wave lengths with the variety of clay mineral in the absorption chamber. Preliminary measurements suggest that certain clay minerals have characteristic infra-red absorption patterns, and that the absorption curves may be of help in the identification of clay minerals. Examples of absorption curves are shown.

MORPHOLOGY OF OSTRACOD MOLT STAGES

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A culture of living *Cypridopsis vidua* was studied to follow the changes in shell character through successive molt stages. Camera-lucida drawings were made of 500 shells selected at random. Various measurements were compared by graphs. Several adults were sectioned in frontal, sagittal, and transverse directions to study relation of the internal organs to the enclosing shell.

The investigation shows that:

(1) Each molt stage of an ostracod introduces an animal differing from that of the previous stage. Entire new appendages are added, and the function of previous appendages is drastically changed. Each molt must be regarded as a completely integrated living unit, performing locomotion, feeding, respiration, and other life processes. Thus we cannot separate the study of the shell from that of the associated appendages and internal organs.

(2) The size distribution of shells in any one molt is set off from that of adjoining molts. In any one species, the size of shell establishes the molt stage.

(3) Considerable variation occurs within each stage. A comparison of individuals purely by ratio of measurements is not justified.

(4) The shape of the shell changes from one molt to another for accommodation of new appendages and structures.

(5) Young molts of related species are so similar that the species cannot be determined from shell alone. Full character of the adult does not appear until after the last molting.

SPECIATION IN A PERMIAN GASTROPOD GENUS

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In the marine Permian of the American southwest (Wolfcampian to Guadalupian series) occurs an undescribed genus of gastropods, seemingly a slightly modified derivative of *Microdoma* Meek and Worthen (Trochacea). Two species are recognized, one characterized by two pleural ridges and the other by three. The two-ridged species has been recognized in the Hueco limestone of Wolfcampian age at various localities. It can be successfully divided into three statistically distinct population groups, which are treated as subspecies. The three-ridged species likewise is divisible into four population groups, each separated from the other by a considerable time interval.

These two species and seven subspecies are discussed with as much collateral information as to space, time and paleogeographic distribution as can be brought to bear on them.

UNUSUAL SPECIMEN OF LEPIDODENDRON*

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An unusual specimen of *Lepidodendron* was presented to the Illinois Geological Survey by Mr. D. W. Buchanan, President, and Mr. John E. Jones, Safety Engineer, of Old Ben Coal Corporation. The specimen was collected from the roof shale of the Glen Rogers Mine of the Raleigh-Wyoming Mining Company, Glen Rogers, West Virginia. The coal mined is the Beckley bed and lies above the Fire Creek and below the Little Raleigh coal beds. The position of the fossil specimen stratigraphically is near the base of the New River group of the lower Pottsville series of eastern United States.

The fossil is unusual in two respects: (1) The stem or branch had pyramidal leaf cushions associated with *Lepidodendron* and, as reported by Mr. Jones, was unbranched over the entire length of about 12 feet; (2) the attached foliage on the specimen is over 30 inches in length. No leaf apices are present on the specimen to tell their exact length. The unbranched character of the stem or branch is more closely related to *Sigillaria* than to *Lepidodendron*. Unusually long leaves are rare to both genera except for the foliage of *Sigillaria lepidodendrifolia* although in general the leaves of *Sigillaria* are believed to be longer than those of *Lepidodendron*. Thus the specimen would appear to be of Sigillarian origin except for the pyramidal leaf cushions which are, as stated above, a lepidodendroid character.

POSSIBLE ALGONKIAN IN NEW YORK STATE

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Study of the Allens Falls locality and new exposures 1 mile south of Canton suggest that the basal breccias or "wash" at the base of the Potsdam may be of pre-Cambrian age and consist of two entirely different formations.

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The Allens Falls "basal breccia" is a fluvial arkosic fanglomerate consisting of microcline- and orthoclase granites and gneisses; sericitic and micaceous schists; lava flows, from trachytes to glassy latites; with a matrix of quartz, feldspars, sericite, kaolinite, and hematite. Heavy accessories include idiomorphic apatite and igneous tourmaline, large zoned zircons, garnet, epidote, pyroxenes too altered for precise determination—an assemblage vastly different from the mixed rounded tourmaline and zircons of the Potsdam.

These fanglomerates, interlayered with arkoses consisting of 50 per cent quartz, 35 per cent orthoclase, and 15 per cent microcline, are morphologically and genetically undistinguishable from the Connecticut Triassic or the California Sespe. They are preserved in Canyon bottoms cutting Archean granites and marbles and represent sediments formed by violent erosion during intense tectonism (block faulting?), possibly a major Algonkian uplift following Ep-Archean peneplanation.

At Canton the "basal breccia", filling ancient sinkholes in the Grenville marble covered unconformably by the Potsdam quartzite, is a residual regolith of metaquartzites, jaspers, and cherts, an ultrastable mixture concentrated by prolonged chemical weathering, possibly during post-Algonkian peneplanation preceding Cambrian sedimentation. Thus, the hypothetical hiatus between the Allens Falls fanglomerate and the Canton surface deposits may equal a geologic period and represent erosion of several thousand feet of orogenic Algonkian deposits.

SALT BASIN RIM COLLAPSE

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The rim of the Salina salt basin in Michigan, Ontario, and Ohio is marked by a belt of brecciated, fractured, and faulted rock. This is best developed in the Mackinac Straits area where all post-salt, pre-Dundee rocks show collapse features. At the opposite side of the basin in southeastern Michigan and northern Ohio only the less competent layers in the upper Silurian rocks show signs of disturbance. The position of this belt peripheral to the present leached boundary of the salt deposits leads to the conclusion that extensive collapse into salt caves has taken place. The breccia on the rim of the Mackenzie Valley (Northwest Territories) salt basin may have similar origin.

ORIGIN OF POLISHED ROCK SURFACES IN TRANS-PECOS TEXAS AND SOUTHEASTERN NEW MEXICO

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U. S. Geological Survey, Washington, D. C.

In Trans-Pecos Texas and southeastern New Mexico there are clusters of rocks whose surfaces have been polished. The number of polished rocks in a cluster may be large, but few such clusters have been reported though they are widely distributed through the area. All the polished surfaces occurring on boulders and rock walls lie within a 12-foot span from the ground surface up. An examination of the surfaces shows that they have been produced by buffing, and residual oily matter can be extracted from the polished surfaces. It is believed that *Archidiskodon imperator*, *Parelephas columbi*, and *Mastodon americanus* are responsible for most of the polish.

Polishing probably was done about 3000 to 5000 years ago when Folsom man was in existence. The extinction of both the elephants and Folsom man as such is laid to the effects produced by the climatic optimum. The Basket Maker and Pueblo man who followed Folsom man are not known to have recorded a likeness of the elephant though they were proficient in the graphic arts.

OUTLINE OF THE LATE CENOZOIC HISTORY OF SOUTHERN ILLINOIS

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For the purpose of this paper the Late Cenozoic history of Southern Illinois is taken to begin with the completion by erosion of the lowland surface upon which the original formation of brown chert gravels ("Lafayette") was laid down.

Consideration will be given to the revolutionary change in regimen of streams recorded by these gravels, to the weathering and partial cycles of erosion which followed their deposition, and to the drainage pattern that existed at the beginning of the Pleistocene.

The record of the early glacial and interglacial stages will be analyzed in reference to the concept that the brown chert gravels are Pleistocene and mainly interglacial and in reference to other deposits that appear to be the representatives of the Pleistocene.

Attention will be given to the succession of loess deposits and to the Wisconsin valley trains, glacial torrents, and backwater deposits which indicate a history for the Mississippi, Ohio, and Wabash rivers quite different from that recently published by Fisk in which the approach was from the lower Mississippi alluvial valley.

BRACHIOPODS FROM THE ORDOVICIAN OF WESTERN NEWFOUNDLAND

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In western Newfoundland over 40 species of brachiopods, many of them new, occur in rocks classified by Schuchert and Dunbar as the St. George group, Table Head group, Humber Arm group, and Cow Head breccia.

The Lower Ordovician brachiopod fauna of the St. George is a small one including such genera as *Finkelnburgia*, *Diparelasma*, *Pomatotrema*, and *Syntrophinella*.

The brachiopod fauna of the Table Head does not give definite evidence as to the age of the Table Head group. In the fauna there are such genera as *Aporthophyla*, *Rhysostrophia*, *Syntrophopsis*, and others which have been reported from rocks of Canadian age. The presence of a *Tetragraptus-Phyllograptus* fauna at the top of the Table Head appears to indicate a Lower Ordovician age for the group, but the occurrence of very large actinoceroid cephalopods in the lower part of the Table Head suggests an age much younger than even the Chazy with which the Table Head group has been correlated.

In the Humber Arm group only a few inarticulate brachiopods have been found.

Many of the brachiopods found in the St. George and Table Head also occur in the blocks in the Cow Head breccia. Several genera such as *Nanorthis*, *Apheoorthis*, *Syntrophina*, *Glyptotrophia*, *Leptella*, and *Orthis* which have been found in the blocks in the Cow Head do not occur *in situ* in western Newfoundland. These genera have been reported elsewhere in North America from rocks of Canadian age.

PETROLOGY AND GENESIS OF GORE MOUNTAIN GARNET, NEW YORK

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The giant, hornblende-sheathed garnets of the Barton deposit on Gore Mountain have long been a major source of abrasive garnet and one of the puzzling problems of Adirondack petrology. The

deposit is exposed as an elongate east-west trending body between quartz-pyroxene syenite on the south and garnetiferous metagabbro on the north. The garnet crystals, several inches to a foot or more in diameter, are individually enclosed in shells of coarse black hornblende and set in a coarse, granoblastic matrix of hornblende, plagioclase, and hypersthene. Field and laboratory studies establish: (1) a bulk compositional equivalence and a mineralogical and textural gradational relationship between the garnet deposit and the contiguous metagabbro; and (2) an intrusive relationship between the syenite and the garnet deposit, along the periphery of which the syenite is hybridized and carries xenocrystic garnet. The microscopic corona garnet in the gabbro, the small poikiloblastic garnet in the metagabbro, the giant hornblende-rimmed garnets of the deposit proper, and the garnet xenocrysts in the syenitic hybrid all have essentially the same composition, roughly equivalent to 40 per cent pyrope, 43 per cent almandite, 1 per cent spessartite, 14 per cent grossularite, and 2 per cent andradite.

It is concluded that the parental garnet type is that which occurs typically as coronas in the least modified gabbro; that this corona garnet is deuteric in origin; that all the other textural types were derived from this parental type by metamorphic recrystallization associated with the rise of the syenite magma; that the garnet deposit is simply a highly reconstituted peripheral portion of the gabbro body; and that the giant size of the Barton garnets must be attributed to structurally localized and unusually favorable or prolonged conditions of recrystallization. Alternative hypotheses of origin by direct magmatic crystallization or by metamorphic reconstitution of a Grenville inclusion must be rejected on the basis of the composition and high specific gravity of the garnet.

EARTH SCIENCE PROGRAM OF THE OFFICE OF NAVAL RESEARCH

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Two years ago Doctor Roger Revelle reported to the Society on the plans for the ONR research program in the Earth Sciences. This paper is a progress report on the various projects now being supported by ONR funds. The sciences involved are submarine geology, geology, seismology, geochemistry, volcanology, terrestrial magnetism, gravimetry, sedimentation, glaciology, and Arctic and Antarctic exploration. The Geophysics Branch of the Office of Naval Research has supported a total of 42 projects of which approximately 30 are still active. Some of the more typical projects are elaborated upon, and, where possible, results are given. The functions of the National Research Council Advisory Committee to the Geophysics Branch are described.

ARROJADITE AND GRAFTONITE FROM THE NICKEL PLATE MINE, SOUTH DAKOTA*

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The iron phosphate described by Headden in 1891 from the Nickel Plate mine, South Dakota, was re-examined. This material, not originally named, was later termed headdenite by Quensal and Mason, but is now known to be type unoxidized arrojadite. The massive sample appeared homogeneous, but a fresh interior surface showed graftonite, quartz, muscovite, and cassiterite. Thin sections show that the cassiterite occurs as subhedral grains or as thin seams containing rows of halos in the cleavage of the arrojadite. The analysis of arrojadite is: insoluble 0.11, Na_2O 6.40, K_2O 1.74, CaO 2.46, FeO 28.22, MnO 15.78, MgO 1.04, Li_2O 0.09, Al_2O_3 2.66, Fe_2O_3 none, P_2O_5 40.00, H_2O^+ 0.91, F 0.80, total 100.21 less O = F_2 0.34, total 99.87. Optical constants are: α = 1.664, β = 1.670, γ = 1.675, biaxial negative, 2V = 86°, $\rho < v$ strong, X colorless, Y pale green, Z pale yellow green. The three strongest lines in the X-ray powder pattern are 3.04Å, 2.715Å, and 3.22Å. The analyses of the graftonite is insoluble 0.16, MnO 21.81, FeO 30.70, Fe_2O_3 none, Al_2O_3 0.20, TiO_2 none, CaO 6.00, MgO 0.10, P_2O_5 39.66, H_2O 0.60, Li_2O 0.05, Na_2O 0.28, K_2O none, F

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0.20, total 99.76, less O = 0.08, total 99.68. The optical constants are $\alpha = 1.713$ $\beta = 1.719$, $\gamma = 1.739$, biaxial +, $2V = 60°$, $\rho > v$ strong, X = Y = colorless, Z = pink. The three strongest lines are 3.96 Å, 3.21 Å, and 4.18 Å.

ANALCIME SUITE OF IGNEOUS ROCKS, BREWSTER COUNTY, TEXAS

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In southern Brewster County, Texas, a distinctive suite of alkalic rocks containing analcime is present in small laccoliths, sheets, sills, and dikes. The most abundant rock types are plagioclase-orthoclase (orthoclase, soda orthoclase, anorthoclase) rocks with augite, aegiritic pyroxene, olivine, apatite, analcime, and ore minerals. Biotite and hornblende are present in some specimens. Two masses contain nepheline rocks. These rocks have been called analcime basalt, nepheline basalt, trachybasalt, trachydolerite, syenogabbro, syenodiorite, and plagioclase syenite depending upon differences in texture and small but distinct mineralogical differences.

In many of the masses syenitic differentiates containing analcime, alkalic feldspar, aegiritic pyroxene, hornblende, and biotite are present. Blebs, stringers, and small irregular bodies of syenite are common. In a few of the masses much larger bands and irregular masses are common. Some of these appear to be pegmatitic, others aplitic. The manner of occurrence and constant association of the differentiates preclude separate intrusions.

In all the rocks analcime formed late but is present in chilled borders of the larger masses as well as in the differentiates. There is evidence to indicate that it was nearly contemporaneous with alkalic feldspar, hornblende, and aegiritic pyroxene in the differentiates.

The complete suite shows a considerable range in composition and together with the mineral sequence suggests that the magmas were undergoing reaction when solidification occurred. The range of analyzed specimens is SiO_2, 40.17–61.28; Al_2O_3, 13.44–18.75; Fe_2O_3, 1.81–4.21; FeO, 1.53–9.72; MgO, 0.40–12.32; CaO, 1.24–12.55; Na_2O, 2.22–6.44; K_2O, 0.71–6.56; TiO_2, 0.67–3.51; P_2O_5, 0.11–1.04.

PALEOBIOLOGIC IMPLICATIONS OF THE MEASUREMENT OF PALEOTEMPERATURES

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Doctor Urey's method of measuring paleotemperatures by means of the oxygen isotopic composition of fossil shells promises to furnish a quantitative tool for paleo-climatology. Consequently, it could lead to the establishment of a temperature control in the study of fossil assemblages in relation to their temperature environment and, in addition, clarify the relationship between animal geographic distribution and past climatic zoning. The use of fossils as the raw material for paleotemperature determinations requires as a prerequisite the discrimination of inherent, habitat-controlled, burial-induced, and diagenetically introduced isotope variations in the fossil shell. Some of the criteria as well as problems connected with the proper selection of reliable material as amplified by the Cretaceous forms analyzed up to date will be discussed.

STRATIGRAPHIC RELATIONSHIPS OF THE OUTCROP WOODBINE SAND OF NORTHEAST TEXAS*

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Stratigraphic study with W. S. Adkins for the past 4 years, plus much information from many others, permits the following provisional summary.

(1) From Grayson County, southward through Tarrant County, the Woodbine is essentially conformable with, and transitional into, the Eagle Ford. South of Tarrant County, beginning

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within the Johnson-Hill County area, Woodbine bevelling and Eagle Ford overstepping is indicated.

(2) Within the Woodbine-Eagle Ford outcrop of Denton County, the lithofacies contact of these formations descends from a "northern," stratigraphically younger position to a "southern," older position, through a stratally continuous interval. The lithofacies of this interval to the north is "Woodbine," to the south, "Eagle Ford." Available regional zonation data are in a reconnaissance stage.

(3) Excepting synclinal areas, the lower contact of the outcrop Woodbine is unconformable. Supporting data are (1) regional partial removal of subjacent upper Washita formations, (2) overstepping relations in the lower Woodbine, and (3) local presence of a possible subaerial weathering residuum.

(4) *Flabellammina denisonensis* Tappan, described and hitherto assigned as a Woodbine "marker," is related to Washita deposition. The facies relationships of this Foraminifera favor a Buda-equivalent assignation to the lithofacies containing the faunule.

(5) The type section of the Pepper shale contains both Eagle Ford and Woodbine equivalents separated by an unconformity. The restricted Woodbine Pepper is correlative into the upper Woodbine of Dallas County.

(6) The Eagle Ford Tarrant formation in the type area is the basal few feet of a transitional interval between littoral Woodbine and neritic Eagle Ford.

NOMENCLATURE OF FOLDS AND FLEXURES

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Widespread confusion of terminology, if not of ideas, is apparent from an analysis of geologic literature and current textbooks dealing with simple folds and flexures.

In the following groups of geologic terms, the members of each are too commonly used as interchangeable, if not synonymous: (1) regional dip, homocline, monocline, arrested anticline, terrace; (2) anticlinorium, geanticline, arch, dome, anticline, anticlinal; (3) synclinorium, geosyncline, downwarp, basin, syncline, and synclinal. Such ambiguity renders the names useless unless accompanied by elaborate description or graphic illustration. Examples from the literature are cited.

Structural geology terms have a legitimate place, particularly in guiding future students, only if they supplant needlessly empirical descriptions or diagrams or both. In accordance with generally accepted principles of scientific nomenclature, these features are redefined and illustrated in an effort to clarify each one and render them mutually exclusive—anticline, syncline, regional dip, homocline, monocline, anticlinorium, synclinorium, geanticline, and geosyncline.

THE GLACIAL CYCLE

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Conditions prevailing during a typical glacial age of a continental glacier are reviewed in some detail. The meteorological conditions necessary for the growth and advance of an ice sheet, when coldness, humidity, and precipitation are on the increase, are discussed. Conditions necessary for the maintenance of an ice sheet at maximum stand are reviewed. Lastly, conditions during glacial retreat, when decreasing coldness, decreasing precipitation, and increasing wastage favor increasing aridity and eolian action over the till plain with maximum weathering, leaching, and loess deposition are outlined. Sedimentation in both the glaciated and the periglacial areas during glacial advance, maximum stand, and retreat is discussed fully in relation to the origin of glacial gravels and sands, till, moraines, fluviatile deposits, gumbotil, forest beds, and loess.

The thesis is advanced that the length and duration of a glacial age, exclusive of any interglacial time, has been generally greatly underestimated and that the time during which a continental glacier remained at maximum stand has been much greater than generally thought. Further, it is suggested

that the usually accepted estimates of the amount of snow and ice in existence on lands today, mainly Greenland and Antarctica, are fantastic and should be greatly revised downward along with our estimates of the effect that the melting of this snow and ice would have on sea level. Re-examination of the basis for these estimates indicates that we are now much nearer the end, if not actually at the end, of the Pleistocene period than is generally conceived.

ORIGIN OF MINERALIZING EMANATIONS IN THE IRON SPRINGS DISTRICT, SOUTHWESTERN UTAH*

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Iron deposits of the Iron Springs district occur as replacements around three laccolithic bodies of quartz monzonite porphyry. Relations in one of the intrusive bodies indicate that the mineralizing emanations containing iron evolved from parts of the porphyry now exposed. The essential condition for release of iron was a decrease in pressure in parts of the crystal mesh of the porphyry undergoing intense and protracted deuteric alteration. The fact that gaping cross joints were opened in the porphyry indicates that the magma was semi-solid, and that pressures were directed, not hydrostatic. Iron escaped only from those parts of the reacting crystal mesh penetrated by the cross joints, and these, in turn, developed only in outbulged parts of the igneous body, where a late surge of intrusion caused distension of the crystal mesh. Mineralization is associated genetically with outbulges, and only incidentally with high cupolas.

Field relations on which this hypothesis was based, and its practical implications in a search for blind ore bodies were outlined in a guidebook for a field conference in 1947. Additional evidence obtained partly in the other two intrusive bodies confirms and supplements the hypothesis: (1) about 75 analyses for iron content of the several rock types permit quantitative evaluation of deuteric differentiation as a source for the ores of the district, (2) petrographic studies clarify the mineralogic changes involved, and (3) miarolitic cavities that occur sporadically in the zones of cross joints contain the common ore minerals.

LATE CENOZOIC CHRONOLOGY OF THE UPPER VERDE VALLEY, ARIZONA

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The upper Verde Valley of Central Arizona lies between the Mogollon Rim of the Colorado Plateau and the Black Hills Range, a fault-block mountain. The valley was once the site of a lake created by a lava-tuff dam across the Verde River.

Relationships between lake sediments, Paleozoic sediments, a lava sequence, stream gravels, pediments, and faults reveal details of the Cenozoic history of the Verde Valley which are of significance in interpreting broad regional events. In late Miocene time, before the Verde Valley existed, gravels were deposited on what is now the high plateau surface. Headward growth of the Verde River resulted in capture of north- and east-flowing drainage and the excavation of the first upper Verde Valley. In this valley was deposited a great thickness of gravel locally derived in part but also containing pre-Cambrian rock types. Re-excavation then occurred. Pediments developed on the plateau side of the valley at this time. Outpourings of lava then created the dam which blocked the river. Deposition of sediments in Verde Lake was contemporaneous with part of the igneous activity. These and other relationships indicate a Pleistocene rather than Pliocene date for Verde Lake sediments. Lava flows of the Black Hills associated with lake sediments are cut by the main movement along the Verde fault which bounds the Black Hills. Excavation of the lake sediments is now occurring and has resulted in the formation of pediments in the valley.

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GEOLOGY IN SHORE-CONTROL PROBLEMS

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Practical problems of shore control encountered by engineers are described, including the rehabilitation and stabilization of beach areas, the establishment and maintenance of navigable harbor-entrance channels, and the provision of harbor protective works. The pertinent factors of shore-material balance and energy-material balance are discussed, and the importance of geological information to their evaluation considered. Suggestions are made on the manner in which geologists may contribute to the solution of the engineering problems. Some research problems of shore control of particular interest to geologists are outlined.

AGGREGATES FOR CONCRETE

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As concrete structures of larger size and greater life expectancy are constructed and proposed for construction, greater attention has been and must be given to the criteria for the selection of concrete aggregates. Aggregates for such structures must satisfy not only the requirements for strength and gradation but also must contribute to the durability of the concrete in which they are used. Aggregates must therefore be structurally suitable and free from physically undesirable contaminations and must occur in or be processed into particles of suitable size, shape, and gradation. Finally, they must be both chemically and physically compatible with each other and with the portland cement paste with which they will be combined when used in concrete. The designation of a suitable aggregate source must therefore be based on a thorough knowledge of the characteristics of the deposit, the characteristics of the material which may be produced from it, and the economic considerations involved in production, transportation, and use.

Examples are cited to illustrate the application of laboratory test data to the selection of aggregates. Methods for determining the presence of constituents which may become involved in deleterious chemical reactions in concrete, methods for evaluating the effects on concrete durability of thermal properties of the aggregates, and examples of the application of petrographic observations of microstructure to processing and durability are given.

CHARTING FIVE AND SIX VARIABLES WITHIN THE BOUNDING TETRAHEDRA OF HYPERTETRAHEDRA*

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Triangles, tetrahedra, and hypertetrahedra may be used as reference frames for charting variables whose sums equal unity. The number of variables that may theoretically be charted equals the number of vertices in the figure.

Hypertetrahedra of n dimensions are bounded by points, lines, triangles, tetrahedra, and hypertetrahedra of $n-1$ and fewer dimensions. Direct geometric charting within hypertetrahedra is impossible, as such figures cannot be envisaged or constructed; but the variables may be plotted in groups within the bounding triangles or tetrahedra.

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Methods have recently been presented by the writer for charting five, six, or seven variables in the bounding triangles of hypertetrahedra of four, five, and six dimensions. Methods are now given for charting five and six variables within the bounding tetrahedra of hypertetrahedra of four and five dimensions. For seven variables, these methods have little advantage over charting within the bounding triangles.

Analyses are arranged in all possible groups of four variables, and each group is recomputed to equal unity, or 100 per cent. These groups are plotted as points within the bounding tetrahedra; and each point is then projected orthogonally onto some selected tetrahedral face. From an assemblage of such projected points, contour maps are made. Thus five variables are represented by five maps, and six variables are represented by fifteen maps.

Quadriplanar and trilinear co-ordinates are used. Negative co-ordinates and their uses are explained; and methods are given for amplification of scale when needed. For drawing contour maps, empirical arrangements of the tetrahedral faces of the bounding tetrahedra are presented.

EARTH-DAM DESIGN AND CONSTRUCTION

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In the design and construction of earth dams the type of soils laid down in the river valleys is of major importance. The primary factors are stability and permeability. This paper will deal principally with these two characteristics of river-valley sedimentary deposits and their relation to the design and construction of earth dams.

STATUS OF RESEARCH ON COAL GEOCHEMISTRY

(Report of the Coal Geochemistry Subcommittee of Coal Research Committee, SEG)

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(1) Research work in the field of Coal Geochemistry (being any chemistry bearing on the geological processing of coal formation) now in progress in the United States is summarized.

(2) Some background material on certain aspects of the subject is given.

(3) The principal problem confronting workers in this field is believed by the writer to be the determination of the precise chemical constitution of coal. Partial resolution of this problem has been achieved in the past through treating coal by certain techniques familiar to the chemist in other fields of organic chemistry—*e.g.*, study of oxidation, halogenation, hydrogenation and reduction reactions, solvent extractions, etc.

(4) Particularly interesting results have been obtained through mild oxidation of coal by which regenerated humic acids are produced. The chemical structure of these humic acids (and their further oxidation products) are now being studied in several laboratories in an attempt to work back to the structure of the original molecules in coal.

(5) Molecular-weight studies are mentioned, as well as other types of investigation which bear on the fundamental problems of geochemistry.

GEIKIELITE, A NEW FIND FROM CALIFORNIA*

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Geikielite, a magnesium titanate, has been found at the Jensen Quarry, Riverside County, California. The mineral occurs in tiny grains and crystals sparingly disseminated through the crystal-

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line brucite-limestone of the quarry, associated particularly with concentrations of minute grains of flesh-colored spinel.

It is deep red to nearly black, transparent red in thin crystals or fragments. Its specific gravity is 3.79.

Measurable crystals are rhombohedral, with the base dominant, one rhombohedron usually well developed, three others occasionally present. Forms, (0001) $(10\bar{1}1)$ $(20\bar{2}5)$ $(02\bar{2}1)$ $(01\bar{1}2)$.

X-Ray powder photographs, which can be completely indexed, confirm the structure to be C_{3i}, with c/a = 2.67, checking with the ilmenite group.

Composition was determined by chemical analysis of carefully purified material: TiO_2 64.9, Al_2O_3 1.3, MgO 31.8, FeO 1.4, MnO 0.4, SiO_2 0.9.

SIGNIFICANT EXPERIENCE WITH THE INVESTIGATION OF FOUNDATIONS FOR A HIGH DAM IN GEORGIA

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The extent to which engineering prejudice and insufficient geological information combined to delay selection of the final site of the dam is reviewed. The investigational procedure required to overcome these obstacles and permit proper adaptation of design to extremely limiting foundation conditions are discussed for the benefit of both experienced and inexperienced engineering geologists.

GIGANTISM, AN IMPORTANT TREND IN FOSSIL INVERTEBRATES

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Gradual increase in size during evolution is a common trend throughout the animal kingdom, and it is clear that the mean size of individuals has increased in many groups. Probably this increase is a result of specialization and increase in complexity. At the taxonomic level of genera and families progressive size increase, herein referred to as gigantism, is one of the best-defined and most prevalent of all trends shown by the fossil record. Although gigantism is best known from the vertebrate record, particularly that of the mammals, there are numerous examples reported in several of the better-known invertebrate phyla. Characteristic examples of invertebrate gigantism are herein discussed, and an attempt is made to analyze environmental factors which may cause strong selection for increasing size. It is suggested that some, perhaps many of the better-documented examples of "recapitulation", involving hypermorphosis and acceleration (de Beer, 1940) are the result of gigantism and phylogenetic allometry. It is quite possible that trends in other characters—for instance, the ammonite suture pattern—may be the result of gigantism accompanied by allometric growth.

WIND ACTION AT MOUNT CARMEL, QUEBEC

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Mount Carmel is 12 miles northwest of Trois Rivieres and 6 miles southeast of Shawinigan Falls. The "mountain" is made of sand and gravel and is 4 miles long and 1½ miles wide and rises 350 feet above the St. Lawrence lowlands. Wind action is apparent on the southwest corner of the mountain

where cobbles and pebbles have been faceted by wind action. Faceting is particularly apparent in a layer of gravel that marks the edge of the steep slope. Probably this gravel "guarded" a terrace above it from which the sand was removed by wind action.

REFERENCE DIRECTIONS AND THEIR USE IN THE MEASUREMENT OF INDIVIDUAL IRREGULAR PARTICLES

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Non-scalar measurements of the attributes of individual irregular particles depend upon the reference directions chosen for measurement. Any given reference direction such as the maximum intercept of an irregular particle may be used to define other reference directions, measures of directional size, directional shape, directional roundness, and space position of the particle with respect to a set of co-ordinates. When reference directions are suitably classified it is possible to derive measures of directional size, shape, and roundness and of space position merely by applying generating principles directly to the reference directions. Scalar size measures used in conjunction with planar or linear directional size measures permit the measurement of overall shape conformance and other directional attributes of irregular particles.

Reference directions are usefully classified by applying or considering (1) the extent to which they require a previously found direction for their definition; (2) their co-ordinate position with respect to the particle; (3) their planar or linear nature; (4) their dependence on the internal structure of the particle or the geometry of the particle. The nature of reference directions and directional measures derived from them is shown by considering selected ones derived from the maximum particle intercept, the axis of least moment of inertia, and a horizontal tangent plane on which the particle is allowed to rest with its center of gravity as close as possible to the plane. Thus, from the first of these most of the commonly used measures are derived, and such measures as the Zingg ratios can be proved to be the quotient of two simpler directional shape measures.

Ten uses for reference directions are pointed out, and some advantages of selecting them to suit the physical environment are noted.

STATUS OF THE TECHNOLOGY OF COAL PETROGRAPHY

(Report of the Coal Petrography Subcommittee, Coal Research Committee, S.E.G.

BRYAN C. PARKS

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This is a report on the present status of coal petrography including discussion of the laboratory techniques of thin-section analysis, polished-profile analysis, broken-coal analysis, and preparation of briquettes and thin sections with powdered coal. The speaker reviews the growing interest in physical composition of coal as determined by petrographic analyses and usefulness of analyses particularly in the fields of coal mining, preparation, and utilization.

IGNEOUS ROCKS OF THE CAPITAN QUADRANGLE, NEW MEXICO

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Igneous rocks of the Capitan quadrangle, New Mexico, occur in the Capitan, Patos, Carrizo, Vera Cruz, and Sierra Blanca mountains, and in numerous small intrusions, dikes, sills, and extrusive flows. The results of quantitative mineralogical analyses and the modes of the rocks are given.

SCORZALITE FROM SOUTH DAKOTA: A NEW OCCURRENCE*

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The mineral association, chemical analysis, and physical properties of scorzalite from a new occurrence are described. Analyzed material from the Victory pegmatite, near Custer, South Dakota, contains 17.06 per cent FeO, 2.93 per cent MgO, and has a Fe:Mg molecular ratio of 3:1. Scorzalite from this locality is the richest in iron of the known members of the lazulite-scorzalite isomorphous series.

INVESTIGATION AND PROPOSED TREATMENT OF CAVED MINE BENEATH 20-STORY VA HOSPITAL

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The proposed 20-story Veterans Administration Hospital at Pittsburgh, Penna, will be founded about 63 feet above the roof of an abandoned and inaccessible caved mine originally from 3 to 6 feet high in the flat-lying Pittsburgh coal seam. Final approval of the site depended on the determination of whether the outcrop fires found in adjacent areas had penetrated the old mine workings beneath the hospital site and whether the 20-story building could be economically constructed over the abandoned mine. The subsurface investigations proved that the mine was not and had not been on fire, and that the caved workings could be grouted to refusal and consolidated to carry the proposed loads.

The preliminary subsurface investigations consisted of 13 3-inch-diameter core borings drilled through the Pittsburgh coal seam for general site exploration in 1946. Air samples collected from the cased and capped holes were analyzed by the Central Experimental Station, Bureau of Mines, Department of the Interior, which reported no CO. This evidence of no mine fire was supported by the normal appearance of the coal and roof shales as well as by the clean fragments of mine timbers found in the gob-filled sections of the old mine.

To permit examination of the caved mine and to demonstrate the effectiveness of grouting as a means of consolidation of the clay and shale gob and the granular roof cave, four 30-inch diameter calyx holes were drilled to average depths of 107 feet into mine rooms located by 3-inch core and fishtail holes. Prior to drilling the fourth 30-inch hole, a five-spot pattern of 3-inch holes on 10-foot centers concentric with the 30-inch hole was drilled and grouted through a packer placed just above the top of the roof cave. The center hole was regrouted in two stages. One thousand fifty four sacks of cement were placed at pressures ranging from 0 to 97 pounds per square inch. The complete consolidation of the roof cave and gob was clearly apparent in the walls of the fourth 30-inch hole, photographs of which are presented.

The coal mine will be grouted on 10-foot centers in four stages inside of a 5-foot centered peripheral line roughly 20 feet outside of the exterior line of the 20-story section of the hospital.

PALEOGEOGRAPHIC SIGNIFICANCE OF CAMBRO-ORDOVICIAN SANDSTONES OF NORTHEAST TENNESSEE

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Sandstones near the contact of the Copper Ridge dolomite (Cambrian) and the Chepultepec dolomite (Ordovician) were sampled in northeast Tennessee. Textural analyses of these samples

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indicate a steady increase in grain size northwestwardly. This observation, together with information on the underlying Conasauga group, implies a general northwest source for the late Upper Cambrian clastics, in contrast to the southeast source (Appalachia) of Lower and Middle Cambrian and Middle Ordovician clastics.

Heavy-mineral and light-fraction studies indicate a probable crystalline source, not necessarily far from this region. The sands are relatively free from fine clastics, a fact probably best explained by the separation of the latter during beach or dune phases, or through long exposure to wave action. In keeping with the latter possibility is the general increase in clay-silt to sand ratio southeastward into the Conococheague limestone equivalent. In Pennsylvania the same southeastward gradation is noted in the Gatesburg dolomite (Copper Ridge equivalent) and Conococheague limestone.

The distribution of the sands implies a linear source subparallel to the Appalachian basin on the northwest. The Cincinnati arch appears the best such source possible. This offers likely evidence for earlier activity along that structure than generally recognized.

A northwestward source for these sandstones might be of interest to oil and gas exploration in view of present interests in deeper drilling. The sandstones, offering among the best possibilities for reservoir rock in the thick Cambro-Ordovician dolomites, probably became thicker and coarser under the Allegheny Plateau region.

HEART-SHAPED CAROLINA BAYS

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The Carolina Bays are of two general types, single and multiple. The single type has one elliptical rim, type (a), or one elliptical outer rim and one or more crescentic, smaller inner rims which are developed usually only in the southeast half of the bay, type (b).

A careful study of the larger-scale aerial photographs of the Carolina bay country shows that many irregularly shaped bays are made up of two or more overlapping single bays of either (a) or (b) type. In some of these the direction of overlap is apparently hit or miss, but in others there is a distinct directional lineation. In general this direction is between west and northwest.

Lineated overlapping single bays give to the parent multiple bay an elongation direction of less azimuth than that of its single-component bays. Where the multiple bay is made of two single bays with the later one slightly smaller, the usual size occurrence, and to the west or northwest of the first formed bay, the usual position occurrence, the resulting multiple bay is usually found to be heart-shaped with the small angle directed southeastwardly. This is due both to the relative position of the later-formed bay and to the counter-clockwise turning of its direction of elongation.

If the meteoritic theory of bay formation is assumed, such heart-shaped, multiple bay is explained by the infall of a tandem pair of meteorites. The trailing meteorite of the tandem would hit the eastward-turning Earth farther west because of its smaller size. The counter-clockwise turning of the axis of elongation of the western of the two bays is explained by the position of its path to the west of the axis of the wind-shock wave cone of the meteor which preceded it.

The explanation given by Douglas Johnson for the formation of heart-shaped bays by artesian and ground-water action is shown to be untenable.

QUATERNARY GEOLOGY OF PART OF THE EAST-CENTRAL SIERRA NEVADA, CALIFORNIA

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In the June Lake district of east-central California, the Sierra Nevada has been uplifted along a number of closely spaced faults, and the rectilinear outline of the range front is controlled by their

pattern. That repeated movement is characteristic of these faults is shown by increasing throw where they cut successively older moraines.

There were at least four ice advances in the Pleistocene. Constructional forms have been destroyed on the two older tills but are preserved on the later ones.

Large quantities of rhyolitic ash and pumice, now a welded tuff, were erupted in the interval between the first two glacial stages. A small basalt flow near June Lake rests on till of the next-to-last glacial stage and was glaciated in part by the last ice advance. Plug domes and flows of rhyolitic obsidian of the Mono and Inyo craters were erupted following the last glaciation.

Mono Lake was much larger in the Pleistocene and during the next-to-last glacial stage had an outlet to the southeast. This spillway connected the Mono Basin with the Owens Valley-Death Valley system of lakes and channels.

REPLACEMENT NAME FOR THE UPLAND FORMATION OF NEBRASKA

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Objection to the use of the formation name Upland (A. L. Lugn, 1930), because of its physiographic implication was expressed by the 1947 State Geologists' Pleistocene Field Conference, and it was mutually agreed that the name should be replaced. The Nebraska Geological Survey has substituted a new name for Upland and established the type locality in Sappa Township, Harlan County, Nebraska, where the formation is well developed. This new name has been approved and has been in use by the Nebraska Survey for some time. This paper describes the formation at the new type locality and discusses its occurrence in Nebraska.

The formation, of Yarmouth age, is a series of silts and clays with minor sands and gravels and includes the Pearlette volcanic ash member, probably the most useful key bed of the Central Plains Pleistocene. It is overlain unconformably by the Crete and Loveland formations and overlies the Grand Island formation west of the Kansan till border. Farther east it rests on eroded Kansan till or on channel fills of Grand Island. At the type locality the formation consists of upper snail- and ostracod-bearing silts and clays that grade downward to sands and gravels that rest unevenly on the Pearlette ash. Below the Pearlette are thin silts carrying some snails and ostracods similar to those above. The formation is widespread in its occurrence. Although no well-developed soil horizon is present at the type locality a well-developed dark soil occurs at the top in other exposures.

NEW GENUS OF BLASTOIDS FROM THE SILURIAN

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A *Codaster*-like blastoid from the Henryhouse formation of Oklahoma possesses accessory plates in the posterior deltoid area. It may shed some light upon the origin of the tripartite posterior deltoid of *Nucleocrinus*.

PROBABLE DEEP-WATER ORIGIN OF THE MARCELLUS-OHIO-NEW ALBANY-CHATTANOOGA BLACK SHALE

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The widespread body of black, bituminous shale called locally Marcellus, Ohio, New Albany, and Chattanooga, seems generally to have been considered as a deposit made near shore in very shallow water.

This paper calls attention to many features which indicate deposition far from shore in relatively deep water—at least below wave base—and to others which are definitely opposed to a near-shore, shallow-water origin. Among the former are the presence of abundant light-weight organic materials; the presence of widespread but very thin beds of phosphate nodules; and the presence of other extensive but very thin siliceous and calcareous beds which seem probably to have been volcanic ash. Among the latter, one of the strongest is the lack of indications of wave action. Such indications should be present if the material had been deposited in shallow water.

Characteristically the black shale grades upward into thin-bedded silty sediments which show "rolled boulders" and other evidences of contemporaneous or interstratal flowage. These are interpreted as slope deposits made between wave base and the general floor of the sea.

It is suggested that the black shales are a trangressive deposit made in poorly aerated water in what was then the deepest part of the Appalachian geosyncline, and were being encroached upon by slope deposits along both the southeast and the northwest sides of the trough.

HIGH-POTASH VOLCANIC ROCKS, ST. FRANCOIS MOUNTAINS, MISSOURI*

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The pre-Cambrian of the St. Francois Mountains of Missouri is characterized by acidic igneous rocks including granites, intrusive porphyries, and volcanics of various types. There are also some regionally distributed small gabbroic intrusions. The felsite flows are divided into two groups, both of which are characteristically high in potash feldspars. The feldspars of the younger group are characteristically perthitic. The feldspars of the older group and the rocks as a whole are high in potash and deficient in soda and lime. These rocks, especially the very high-potash ones, are unique. The distribution, petrographic character, and chemical composition of these rocks are given.

SYSTEM K_2O-MgO-SiO_2

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The phase diagram of the more geologically significant portions of the condensed system has been determined by the quenching technique. Four new ternary compounds were found and their thermal relationships determined. Their compositions are $K_2O \cdot 5MgO \cdot 12SiO_2$, $K_2O \cdot MgO \cdot 5SiO_2$, $K_2O \cdot MgO \cdot 3\ SiO_2$, and $K_2O \cdot MgO \cdot SiO_2$ (?). The first of these may possibly occur naturally but has not been reported. The second and third appear to be isomorphous with leucite and kalsilite respectively, and the last is of comparatively little geologic interest. Composition and temperature have been determined for 23 of the invariant points occurring in the system. The geologic significance of the diagram in connection with the determination of the stability relationships of biotite is discussed, and a synthesis of phlogopite from a K_2O-MgO-Al_2O_3-SiO_2 glass at a temperature of 900°C. and 15,000 P.S.I. water pressure is reported. Those studies were made at the Geophysical Laboratory during 1947–1948 on a Carnegie Institution of Washington fellowship.

STRUCTURE OF THE ROCKY MOUNTAINS IN SOUTHERN ALBERTA AND BRITISH COLUMBIA

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The folded and thrust-fault type of structure typical of the Rocky Mountains of Southern Alberta and British Columbia shows many high-angle westward-dipping thrusts, a number of closed folds

* Presented by permission of Edward L. Clark, State Geologist of Missouri.

with both limbs dipping to the east, a few underthrust faults, and in places folded faults, some of which have in turn been faulted. These structures are closely related to the varying competency of the rocks in the stratigraphic succession.

The Lewis overthrust, which at the Montana-Alberta boundary is a low-angle fault, swings sharply to the west and then to the north at North Kootenay pass where it cuts out of the pre-Cambrian formations into the overlying Paleozoic formations and here it takes on a westward dip of 30° to 40°. This is explained by folding of the Lewis fault. This fault is traced northward for about 100 miles, and evidence of its folded character is noted at outlying klippes such as that of Crownsnest Mountain.

The structural trend of the folded Paleozoic-Mesozoic succession bends sharply to conform with the trace of the bend in the Lewis overthrust suggesting that the thrust may have come from the south or southwest rather than more directly from the west. This is discussed in conjunction with that of folded faults, and plan and section diagrams illustrate the structures.

The age of the Rocky Mountain orogeny for this area is probably Eocene or even later as there are several thousands of feet of Cenozoic strata apparently conformable with the underlying Cretaceous involved in the folding.

VARIATIONS IN DIFFERENTIAL THERMAL-ANALYSIS CURVES OF SIDERITE

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Differential thermal-analysis curves of siderite obtained from samples minutely ground, diluted, variously packed, and combinations thereof are shown frequently to suppress the endothermic loop associated with the loss of CO_2. The effect of these variations on siderite DTA curves, which involve the loss of CO_2 followed by oxidation of FeO, is attributed, in part, to the diffusion of gas, both ways, through a packing and to differences in heat transfer.

FAUNAL FACIES IN THE LATE CRETACEOUS MARINE DEPOSITS OF WESTERN CANADA

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The Upper Cretaceous marine formations of the Canadian Great Plains consist predominantly of gray, friable, poorly laminated, noncalcareous shale. In this shale, and particularly in the ferruginous or calcareous concretions occurring with it, are found remains of mollusks representing several successive faunas in time but essentially a single ecological facies. For convenience this may be called the shale facies. Good examples occur in the Alberta, Lea Park, lower Pakowki, Bearpaw, and Riding Mountain beds. In contrast to this are the marine sands, usually occurring as local members within the shale formations. These sands are fine-grained, often clayey or banded with shale, not usually indurated, and in some cases glauconitic. They contain locally rich faunas that are more indicative of the neritic zone, and which may be said to represent the sand facies. Such faunas occur in the Bighorn (=Cardium), the Birch Lake, the middle Pakowki sand members, the upper Bearpaw sand members, and the Eastend formation. The contrast may be best illustrated by comparison of two faunas from the Belanger member of the Bearpaw formation in southwestern Saskatchewan. One of these occurs in ironstone concretions and represents the shale facies, the other in soft sandstone and represents the sand facies. The Belanger shale fauna is characterized by abundance of cephalopods such as *Baculites* and *Scaphites*, and by *Inoceramus*, *Protocardia*, and *Liopistha*. The Belanger sand fauna is predominantly composed of pelecypods such as *Cymbophora*

and *Tancredia*, and includes numerous shark teeth. It is concluded that faunal comparisons in the Upper Cretaceous marine formations of the northwestern Great Plains must recognize the distinction between these two possibly contemporaneous facies.

PHASE EQUILIBRIUM RELATIONS IN THE QUATERNARY SYSTEM K_2O-MgO-Al_2O_3-SiO_2

(Preliminary Report)

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Phase-equilibrium studies are in progress or have been completed on six triangular joins within the quaternary system. Data are complete for the joins leucite-forsterite-silica, leucite-forsterite-potassium disilicate, and cordierite-forsterite-leucite; nearly complete for the joins leucite-clinoenstatite-potassium tetrasilicate and cordierite-leucite-silica; and in progress on the join cordierite-clinoenstatite-leucite.

Only one join, leucite-forsterite-silica, is a ternary system within the quaternary system. This ternary system is, therefore, a composition plane which locates a temperature maximum in each quaternary univarient line which pierces this plane and thus effectively partitions the quaternary system. During crystallization, no liquid can cross this composition barrier. This ternary system illustrates very strikingly the direction of change of composition in residual liquids from the fractional crystallization of a simplified magma. The femic constituents (in this case olivine, forsterite, and pyroxene, clinoenstatite) are nearly completely removed first, leaving residual liquids that are potash-alumina silicates. Appropriate compositions in the system, even though there is less than 0.5 per cent forsterite in their total composition, crystallize the femic constituent clinoenstatite first and yield a residual liquid almost quantitatively free from the femic constituent.

The phase-equilibrium data for the six joins are the first evidence bearing on the mutual stability relations of the rock-forming minerals—olivine, pyroxene, cordierite, leucite, potash feldspar, spinel, mullite, tridymite, and cristobalite—in this quaternary system. There is evidence for solid solution in cordierites, and solid solution between leucite ($K_2O \cdot Al_2O_3 \cdot 4SiO_2$) and $K_2O \cdot MgO \cdot 5SiO_2$ and between $K_2O \cdot MgO \cdot 3SiO_2$ and kalsilite ($K_2O \cdot Al_2O_3 \cdot 2SiO_2$).

MODES OF EVOLUTION DISCERNIBLE IN THE TAXONOMY OF THE SNAKES

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The snakes form the reptilian order Serpentes, which corresponds morphologically to a single family of lizards. Evoution of a number of families roughly equivalent to the total families of lizards may be regarded as the justification for placing the snakes as a separate order.

There are two sharply opposed theories of the origin of snakes from lizards. My own is that the ancestral lizard type was a grassland form with elongate body and tail and reduced limbs, with well-developed ventral scales and eyes; the Walls theory (Walls, 1940) is that the snakes are derived from a limbless elongate burrowing type with extremely degenerate eyes, presumably without ventral plates and with a short tail.

Evolution within the snake group consists of a complex combination of progressive evolution, in which parallel trends are discernible, with adaptive radiation in the major habitats—terrestrial, arboreal, subterranean, and aquatic—and with food specialization.

Four levels of progressive evolution may be recognized, the last of which consists of two parallel types. Each of these levels exhibits one or more generalized families, in which adaptive radiation

is evident, and several specialized families, which result from specialization in a single habitat or food niche. It is important to bear in mind the nonequivalence of specialized and generalized families.

The successive evolutionary levels, with examples of both generalized and specialized families, and with an account of the criteria of habitat adaptation, are discussed.

RADIOGRAPHIC METHODS IN GEOLOGY*

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X-rays have been successfully applied to many fields of science since 1895. The use of X-rays in diffraction work is well known. Radiography, less well known and therefore less widely used, is the method of taking shadow pictures of internal structures by differential absorption of X-rays, the shadows forming an image on a photographic emulsion. In microradiography X-rays are used to take shadow pictures of microspecimens and microstructures on extremely fine-grained film, and the image is examined under magnification. In body-section radiography pictures of selected planes in a specimen are obtained.

In paleontology, calcareous, siliceous, pyritic, and phosphatic specimens have been radiographed, revealing internal structures. Where there is a differential absorption of the X-rays, the method greatly simplifies preparation of specimens and in certain cases reveals factual information not otherwise available. Body-section radiography has been used to locate fossil specimens within a rock. Improvement in techniques should make it much simpler to examine selected planes in skulls and other specimens. Microradiography has been successfully applied in the study of microfossils—for example, showing arrangement of foraminiferal chambers.

In economic geology, classification of coal as to foreign mineral content has been aided by radiography. Coal sections are radiographed to ascertain size, distribution, and arrangement of mineral grains. Mineral associations so determined are probably unobtainable in any other way without disturbing the bedding.

In petrology, microradiographs of metalliferous rocks have shown more data on opaque mineral inclusions and cleavage patterns than microscopic examination by reflected or polarized light.

RESEARCH IN COAL PALEOBOTANY SINCE 1943

(Report of Subcommittee on Coal Botany of the Committee on Coal Research, S.E.G.)

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This discussion is limited to studies in plant microfossils, chiefly fossil spores and pollen obtained from coal, which have the precise correlation of coal beds as a chief objective. Fundamentally this is accomplished by virtue of ecological relationships reflected in the various microfossil assemblages. Most of the ancient plants produced some distinctive microfossils, and probably the composition of a fossil flora is more adequately represented by means of microscopic fossils than from any other common source.

In practical use microfossil assemblages may be matched arbitrarily, proportionate representation of similar species being accepted as evidence of correlation if the coal type is not very different and the distance between sample locations not too great. Comparisons may even be made between the microfossil content of natural benches or layers of coal beds.

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Recent studies, some fundamental and others for practical purposes, published in Britain, the Soviet Union, Australia, and America, are briefly reviewed. The increasing number of institutions sponsoring such studies indicates that the various kinds of minute plant fossils will have a much wider use in the future. The present status of plant microfossil studies in America is outlined in particular.

STATUS OF COAL RESOURCE STUDIES

(Report of the Coal Resource Subcommittee of the Coal Research Committee, SEG)

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The coal resources of the United States have been estimated several times in various ways. Most estimates have been made on the basis of thickness without regard to depth. Recent revisions in some fields show the need for general revision of estimates of coal resources of the United States. Inasmuch as depth to a considerable degree determines the order of removal, new estimates should probably be made on the basis of both thickness and depth. Such estimates should be made so that both potential or inferred resources and immediate or indicated resources can be differentiated. Estimates of proved or measured reserves are also desirable. Data necessary for estimation of resources of the three categories are discussed. Reference to recent, current, and projected coal-resource studies are made.

DETAILED STUDIES OF SUBMARINE CANYONS AT LA JOLLA, CALIFORNIA

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Exploration of the two submarine canyons which extend in almost to the coast on either side of Scripps Institution is continuing. Observations by a diver, Frank Haymaker, along with his photographic record, show the general appearance of the precipitous walls near the canyon heads. The abundant pholad borings found in the vertical or overhanging canyon walls testify to a relatively recent age of canyon cutting. This form of weathering should reduce the cliffs to gentle slopes in the course of time. More definite evidence of the recency of submergence comes from the Quaternary alluvium found on the steep-walled gullies at the head of La Jolla Canyon. This material is entirely comparable to the Quaternary alluvium of the adjacent coasts.

Changes in the fill of the cayon heads has been ascertained recently by echo-sounding profiles (fathograms). Each time a survey is made, profiles are run in duplicate to test the accuracy of the method. The most minute details can be reproduced by these surveys which are made along very exact ranges. Changes of as much as 6 feet have been discovered during a 6-month interval. One gully was observed to have deepened while the next one had been filled to a lesser extent. Changes in the deeper portions of the canyons, beyond depths of about 70 feet, are difficult to determine by echo soundings since the steepness of the walls makes it impossible to get good echoes from the canyon floor.

TRIVOLI SANDSTONE OF WILLIAMSON COUNTY, ILLINOIS*

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The sandstone which outcrops in the northern half of Williamson County in the southern part of the Illinois Basin is tentatively correlated with the Trivoli sandstone of Western Illinois which is

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believed to be equivalent to the basal part of the Missouri series of Iowa. It has been identified primarily from diamond-drill cores from which samples were taken. It occurs a short distance below Coal No. 8 and overlies a shale above the Third Cutler Rider Coal.

The sandstone is a subgraywacke type of arenite corresponding to Krynine's classification of a low-rank graywacke. Typically the rock is light gray, weathering to reddish brown on the outcrop. On the average 60 per cent of the detrital fraction is quartz of various types. The remainder is composed of abundant rock fragments, potash and sodic plagioclase feldspars, and chert. The matrix is of finely comminuted micaceous, argillaceous material. Chemical cements are present in small amount, mostly of secondary silica with some carbonate present. This mineralogical composition is in marked contrast with lower Pennsylvanian sandstones in Southern Illinois which are typically of the orthoquartzite clan. The basal 2–3 feet of the sandstone is conglomeratic and is thought to lie unconformably on the shales beneath.

APERTURE OF *CONULARIA*

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The lobes closing the aperture in *Conularia* s.l. have been generally misconceived as triangular extensions of the faces, their length equal to, or less than, half the diameter of the opening. Recent work shows that the lobes are untapering and may be longer than the complete diameter of the aperture. Some of the implications of these facts will be discussed.

TIME-STRATIGRAPHIC FACTORS IN REGIONAL ANALYSIS

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Studies of isopachs, lithofacies, biofacies, and paleogeologic and paleogeographic maps of Paleozoic intervals in the north-central United States reveal the influence of contemporary tectonics on the sedimentary and biologic history of the region. These studies disclose the fact that few stratigraphic breaks may be traced over the entire tectonic framework. Breaks recognized in the outcrop belt, on the stable shelves or in the geosynclines, seldom persist into intracratonic basins. Therefore the accepted systematic and series boundaries are generally unsuitable for regional studies involving a number of tectonic provinces. Certain breaks, recognizable in intracratonic basins as well as on the shelves, divide the stratigraphic column into units whose boundaries at least approach synchroneity over broad areas of the craton. These breaks, discordant to the classically accepted time-stratigraphic units, raise the recurrent problem of time-stratigraphic classification. This problem is reexamined in the light of new methodology, new concepts, and the wealth of available subsurface data.

PERIGLACIAL BOULDER FIELD IN NORTHEASTERN PENNSYLVANIA*

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The Hickory Run Boulder Field in northern Carbon County, along a valley flat near the headwaters of Hickory Run, lies within the Illinoian drift area, just beyond the border of the Wisconsin

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drift. The boulder field is irregular in outline, and roughly 500 by 2000 feet in extent. The overall appearance of the field is one of striking flatness. The surface is a jumbled mass of bare, unsorted, loosely packed blocks and boulders up to 25 feet in length. The boulders are of quartzitic sandstone and conglomerate of local derivation. Many boulders show pitting, splitting, rounding, and discoloration by weathering in place. Scattered excavations show absence of any finer interstitial material down to water level, at a depth of several feet. Bordering the boulder field are wooded slopes of moderate declivity, with numerous projecting blocks and scattered blocky patches.

The morphology and lithology of the boulder field, together with its present condition of stagnation and decay, are best explained on the basis of origin under periglacial climatic conditions when the Wisconsin ice sheet lay near by. The blocky material is believed to have been supplied by intensified frost action, and carried downslope onto the valley flat by solifluction and frost heave. Climatic amelioration accompanying deglaciation would then account for later slackening of mass movement, stabilization of slopes, and resumption of normal erosive processes, with gradual washing away of finer material originally intermixed with the boulders.

STANDARD FOR GRADING TOPOGRAPHIC TEXTURE

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A study of topographic texture, or drainage density, was undertaken to derive a ratio which will grade the texture on contour topographic maps and to establish limiting values of this ratio for "coarse", "medium", and "fine" texture.

Testing of several possible ratios resulted in selection of the ratio of the number of crenulations on that contour having the maximum number to the length of basin perimeter. Each outward bend in the contour is considered to represent a stream channel and therefore to reflect the actual spacing of drainage lines even though they are not shown on the map.

The texture ratio is expressed by the equation $T = N/P$, where T is the texture; N the number of crenulations on the selected contour; and P the drainage basin perimeter in miles.

Size of basins must be considered in determining the mean value of the texture ratio for a region. The mean value may be taken as the ratio of the sum of the products of the areas times the texture ratios of each basin to the sum of the areas of the basins.

Mean values of the texture ratio were determined for selected regions from recent large-scale topographic maps and air photographs. The following standards are suggested for three texture grades: coarse, below 3.9; medium, 4.0–9.9; fine, above 10.0.

Sample topographic maps of each texture grade on three common map scales have been prepared to assist in visual estimation of the texture ratio.

GROWTH STAGES IN FOSSIL OSTRACODES*

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Principles for the rate of growth in Arthropoda as applied to ostracodes, the number of growth stages that occur, and growth factors (the percentage of increase in size between molt stages) are discussed. It is proved that, according to available data, Hans Przibram's growth factor of 1.26 for all Arthropoda does not apply to ostracodes. Limitations inherent in the study of growth stages of fossil ostracodes are pointed out. Growth stages are illustrated for three species of Permian ostracodes from the Glass Mountains of Texas.

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PLEISTOCENE GEOLOGY OF THE ATLANTIC COAST OF NORTHERN MOROCCO

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Elevated marine platforms, one extensive marine sedimentary formation, and three alluvial deposits are believed to record a succession of strand lines on the Atlantic coast of Northern Morocco. The former strand lines lie at altitudes of 200 m., 165 m., 140 m., 110 m., 85 m., 70 m., 53 m., 35–40 m., 23 m., 15 m., 9 m., 5 m., and 1–2 m. above modern sea level. All are younger than mildly deformed rocks of Astian age. Although correlation depends in part upon altimetry, there is no evidence of deformation of the strand lines below 140 m. Intervals when sea level stood lower than that of the present preceded formation of the strand lines at 35–40 m., 23 m., 5 m., 1–2 m., and modern sea level. Other such intervals may have existed.

Eustatic changes of sea level, consequent upon changes in the magnitude of continental ice caps, are presumably reflected in at least part of the series. The marine sedimentary formation appears to be contemporary with the strand line of 35–40 m. Correlation of both with the Tyrrhenian stage of the Mediterranean area and with the second ("great") interglacial of Europe is suggested. Further correlation with other areas must await additional data; the local succession is more complex than most which have been proposed. For the present, it provides a local chronology which may eventually be related to those of other areas.

LAGOONAL FACIES OF NEWBY MEMBER, REKLAW FORMATION, MIDDLE EOCENE, IN THE TYLER BASIN, TEXAS

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A marine facies with a rich and varied fauna can be recognized in the Newby members at the south end of the Tyler Basin. The marine facies is separated from the lagoonal by a nonfossiliferous crossbedded sand body that is interpreted as a barrier island. The brackish-water facies of the northern part of the basin shows distinct lithologic features and contains a fauna of only two species, *Venericardia planicosta* Lamarck and *Turritella turneri* Plummer. These two species occur in great numbers. Glauconite is found in both facies.

PETROLOGY OF VOLCANIC ROCKS OF NORTHEASTERN NEW MEXICO

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The igneous rocks described in this paper were collected in an area about 86 by 50 miles in northern Union and eastern Colfax counties, northeasternmost New Mexico. Lava-capped mesas and volcanic cones form promient topographic features. The rocks are classified on a mineralogic basis. Basalts are the most widespread, dacites and andesites occur in subordinate amounts, and alkaline rocks as phonolites and soda trachytes are localized in about 24 square miles in central eastern Colfax County. Petrology substantiates three main periods of basaltic extrusion which physiography indicates: Raton (earliest), Clayton (intermediate), and Capulin (recent). Olivine basalts predominate in all three periods and are mineralogically similar with textural variations. Raton basalts are the most uniform in texture and mineralogy. Clayton flows are predominantly olivine basalts but include olivine basalts with quartz inclusions, analcime basanite, nepheline basalts, haüyne basalt, and oli-

vine-free basalts. Red Mountain dacites have built volcanic cones and occur as plugs and necks. The alkaline suite is sodic. Chico phonolites occur as flows chiefly; and Slagle trachytes associated with tinguaites and analcime microfoyaites occur in lesser amounts than the phonolites and are usually intrusives. The sodic rocks fall in line with the other alkaline groups which occur along the eastern front of the Rocky Mountains from British Columbia to Mexico. Dike rocks include leucocratic varieties as hornblende dacite, phonolite, tinguaite, and analcime microfoyaite; and melanocratic varieties as olivine basalt and lamprophyres (vogesite and monchiquite). The diverse rock types are believed to have originated from a parent olivine basalt magma.

HYPSOGRAPHIC ANALYSIS OF FLUVIAL LANDFORMS

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In order to describe quantitatively the landforms produced in successive stages of the fluvial erosion cycle individual small drainage basins have been subjected to hypsographic analysis. Areas enclosed between each contour and the basin perimeter are measured by planimeter and plotted against elevation.

To make comparisons among basins of different sizes all values are computed as percentages. The abscissa represents ratio of area enclosed by a given contour to entire basin perimeter; the ordinate represents ratio of height of contour above basin mouth to total range in elevation present in basin.

Hypsographic curves thus obtained show an orderly series of form changes from youth through maturity to old age. A figure of reference is provided by a solid bounded on the sides by the vertical projection of the basin perimeter; above and below by parallel horizontal planes passed through the highest and lowest points of the basin. Of this volume, the part below the ground surface may be computed as the area below the hypsographic curve and is therefore named the subsurface integral. It is expressed as a percentage of the entire volume of the reference solid. Values range from about 80 per cent in early youth to as low as 17 per cent in old age and are between 40 and 60 per cent in full maturity.

An exponential equation has been devised whose curves approximate the typical percentage hypsographic curves. Thus for every drainage basin a theoretical curve can be fitted and the stage of development expressed as an exponent in the equation.

ANALYSIS OF ROCK-FORMING MINERALS BY SPECTROCHEMICAL METHODS IN PETROLOGICAL RESEARCH

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The possibility of using spectrochemical methods of analysis for determining the chemical compositions of rock-forming minerals in petrology has been examined, with a view to making both more unique and rapid characterizations of rocks than is at times possible by conventional petrographic methods. Such methods can at least provide data to supplement and check those obtained by optical crystallography, if not largely replace them.

Methods have been devised for determining the major and important minor constituents in garnets and ferromagnesian minerals. Work on micas and feldspars is in progress and will be reported later. The methods are applicable for analyzing rocks and minerals separated from the rocks. Samples weighing as little as 1 mg. may be accurately analyzed which makes it possible to study

individual mineral grains and fragments of zoned crystals. Actual mineral samples of accurately known chemical analysis were used as standards. In addition to the major constituents, minor elements, such as Cr, Ti, V, etc., which are known to influence certain optical properties, can be determined simultaneously. One limitation is the necessity of determining only total iron.

FACIES RELATIONS OF UPPER CHESTER FORMATIONS OF ILLINOIS BASIN*

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Although the five uppermost formations of the standard Mississippian section—the Menard, Palestine, Clore, Degonia, and Kinkaid—are alternating limestone-shale and sandstone-shale units, the patterns of lithologic variation within these formations are in general similar. Isolithic maps and cross sections show that in each formation the relative amount of shale increases toward the northeast, of sandstone toward the west, and of limestone toward the south. In the region of greatest lithologic differentiation near the center of the Illinois basin, these rocks appear divisible into nine alternating limestone-shale and sandstone-shale units rather than the five which are recognizable in the type area of these formations on the southwestern rim of the basin.

ARTIFICIAL QUARTZ BY HYDROTHERMAL METHODS

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Quartz has been grown by several investigators, but obtaining continuous growth to produce large single crystals is a special problem. The present investigation, sponsored by the U. S. Army Signal Corps, has canvassed systematically the growth fields for a range of concentrations of NaCl, NaCl with alkalinity adjusted with NaOH, at 400°C., with and without temperature gradient, in the range of 3000 to 6000 psi, using fused silica as source material and AT-cut plates (crystalline) as seeds. The results are presented, the effect of the critical temperature is discussed, and suggestions are made regarding the chemical reactions involved.

PROCESSES OF VALLEY WIDENING

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Studies of local widening in canyons of the Colorado Front Range near Colorado Springs show detailed evidences of the processes involved.

The streams of the region are typically ephemeral ones subject to repeated floods resulting from torrential runoff. These conditions are believed to have been uniform for a long period of time.

The widening results in small, flat-floored basins usually associated with tributary drainage junctions. The basin floors are thinly alluviated except for numerous bedrock exposures along modern and abandoned channels.

The processes involved are: (1) retreat of valley sides by weathering and local corrasion by streams; and (2) shifting of channels as a result of alluvial plugging at the basin head and by tributary deposi-

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tion on the basin floor. Repeated shifting of the channel over a long period and flood scour to an average depth produces a flat bedrock floor.

These valley-widening processes are believed to be significant in the development of prominent piedmont flats in the region.

MESOZOIC GEOLOGY OF THE SOMALI-ETHIOPIA AREA

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The Somali plateau of East Africa, covering most of eastern Ethiopia, British Somaliland, and former Italian Somaliland, is largely underlain by Mesozoic sandstones, shales, limestones, and evaporites. These strata form a sedimentary section probably over 5000 feet thick, studied for 6 months during 1947.

Near the Gulf of Aden and the East African rift valley depressions, the highly dissected plateau escarpment towers more than 3000 feet above the graben area to the northwest. Numerous faults of Cenozoic age cut the Mesozoic beds. To the southeast deformation diminishes, the land surface becomes lower, and the rocks dip moderately toward the Indian Ocean.

A nonfossiliferous basal conglomeratic sandstone, probably Lias in age, and of varying thickness, overlies basement granites and schists. Above this are Jurassic limestones, shales, and marls, followed by a thick evaporite section, chiefly of gypsum, which lies between upper Jurassic (Portlandian) and lower Cretaceous (Barremian) beds. The Cretaceous section includes additional limestones and evaporites and, at the top, a thick nonfossiliferous sandstone, probably of Turonian age, characterized by exceptional development of lateritic and other loiponic deposits. Eocene limestones and evaporites appear in the eastern part of the plateau. Cenozoic volcanics lie in small, widely separated areas as much as 300 miles from the East African rift valley, the nearest center of widespread volcanism.

MEMBERS OF THE GLENWOOD FORMATION IN NORTHERN ILLINOIS AND SOUTHERN WISCONSIN*

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In this region the Glenwood formation consists of four members, which will be named. The first or basal member is composed principally of sandstone and siltstone, the second of dolomite and sandstone, the third of sandstone, and the fourth or uppermost member of very argillaceous sandstone and shale. A thin sandstone at Sterling, Illinois, may represent local development of a fifth and youngest member, but its status is uncertain. The members are very impure and show sharp lateral changes but are lithologically distinctive. The distribution and thickness of the members is very irregular. Although the members have been considered facies by previous workers, they are thought to represent successive time units. The thickness of the Glenwood formation ranges from a few inches at places in Wisconsin to 102 feet at Mendota, Illinois. The formation rests unconformably on the St. Peter sandstone and is separated from the overlying Platteville dolomite and limestone by a diastem. Minor unconformities are present locally between the lower three members. The Glenwood strata appear to have been laid down in a shallow sea where physical conditions varied greatly and changed rapidly. The formation is regarded as the initial deposit of the Mohawkian submergence.

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STRUCTURES OF THE KALKBERG FRONT NEAR CATSKILL, NEW YORK (EXHIBIT)

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A series of cross sections, with accompanying maps, on the Kalkberg Ridge southwest of Catskill, New York, will be exhibited, showing the greatly imbricated and folded structure in the Silurian and Lower Devonian limestones along a narrow belt just west of Highway US 9-W, easily accessible to visitors or classes. These have been carefully measured in the field and plotted on a scale of 50 feet to the inch, both horizontal and vertical.

TUNNELS THROUGH SEDIMENTS

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Technique and cost of tunneling through earth are primarily determined by "stand-up" time of earth at roof and face and by bearing capacity of tunnel bottom. Depending on behavior of ground in tunnel, the engineer distinguishes between firm, raveling, running, flowing, squeezing, and swelling ground. Well-compacted sandy clay and dry or moist loess constitute firm ground, cohesionless sand above the water table or in compressed air tunnels running ground, below the water table flowing ground. Coarse silt behaves above water table or in compressed air tunnels as raveling and below water table as flowing ground. Soft clay is likely to squeeze, and highly plastic but well-compacted clay may swell.

Most earth tunnels are located at depths of less than 80 feet below ground surface. Therefore advance information on tunneling conditions can be obtained by boring, sampling, and testing. The classification of the soil types according to their behavior in the tunnel is part of the duty of the engineer in charge of boring and testing. However, since it is seldom practicable to make more than one boring for every 200 feet, the boring records commonly leave a wide margin for interpretation. The tasks of the geologist consist in constructing a geologic tunnel profile compatible with the geologic history of the deposit and in informing the engineer on the most unfavorable deviations from the ideal profile which may conceivably be encountered, for instance buried channels or soft pockets which were missed by the borings.

RELATION OF SERPENTINE TO UPPER TRIASSIC OVERTHRUSTING IN NORTHEASTERN OREGON*

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In the Aldrich Mountains, which form part of the Strawberry-Ochoco spur of the Blue Mountains several thousand feet of Upper Triassic graywackes, tuffs, and mudstones lie on a basement of metamorphic rocks that probably are Paleozoic. The Triassic beds are well indurated but unmetamorphosed. The Paleozoic (?) rocks comprise schistose greenstone, chert, clastic sediments, and dioritic intrusives, and have been intensely brecciated over large areas.

In an arcuate strip 2–3 miles wide and about 10 miles long, partly concealed by Tertiary lavas, the Triassic is essentially vertical, contains numerous lenses of intensely brecciated Paleozoic (?) rocks and gabbro, and is cut by lenses of highly sheared serpentine up to a mile wide. The breccias and serpentine in general lie parallel to the Triassic beds, and within half a mile of their base. Sedimentary breccias containing fragments of the Paleozoic (?) rocks, gabbro, and serpentine are associated with the tectonic breccias and interbedded with shales and graywackes.

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The intense brecciation of the older rocks, and intercalation of tectonic breccias in the Triassic beds in association with sedimentary breccias of similar composition, are believed to indicate extensive erosion-thrusting in the early Upper Triassic. The gabbro and serpentine lenses in the overthrust complex must be regarded as tectonic units rather than magmas, and masses of serpentine in the Triassic elsewhere in the region probably are likewise "cold" intrusions. The degree of shearing in the serpentines and peridotites of the region appears to be directly related to the local intensity of deformation.

PREGLACIAL AND INTERGLACIAL DRAINAGE OF INDIANA

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The name Teays has been applied to what was the major preglacial valley of Indiana. This valley was really part of the route to the Mississippi of the Kanawha River. In places in Indiana this valley is buried beneath more than 400 feet of drift. Its cross profile has a mature character in the upper part within which is a deeply entrenched valley which has been called the "Deep stage". The mature portion of the valley may correlate with the Parker strath of the unglaciated region. The "Deep stage" is interglacial.

Ponding of the upper Kanawha drainage by a lobe of Nebraskan ice resulted in a permanent diversion of this part to the Ohio. In Aftonian time there remained a stream heading northwest of Chillicothe, Ohio, which continued to flow across Indiana and Illinois to the Mississippi. This unnamed stream developed the "Deep stage" prior to Illinoian glaciation.

The preglacial Wabash River headed in west-central Indiana on the backslope of the Knobstone escarpment, a conspicuous preglacial topographic feature now buried north of the Shelbyville moraine.

The preglacial Ohio headed somewhere between Madison, Indiana, and Point Pleasant, Ohio. Development of the "Deep stage" also occurred down the Ohio and Wabash valleys.

In northern Indiana there existed a fourth and as yet poorly delineated river system which apparently drained northeastward. It is suggested that the now-buried Niagara escarpment may have in part acted as a divide between this river system and the preglacial Kanawha (Teays).

VARIABLE INVERSION TEMPERATURE OF QUARTZ AS A POSSIBLE GEOLOGIC THERMOMETER

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The inversion temperature of quartz has been found to vary as much as 1.89°C. All quartz specimens investigated from high-temperature sources (*e.g.*, phenocrysts in lavas) invert at a lower temperature than quartz from low-temperature deposits (*e.g.*, grown in vugs in limestone). The variation is believed to be due to solid solution, probably predominantly of the interstitial type. The high-temperature modification has a more open structure, permitting more solid solution with consequent lowering of the inversion temperature.

METHOD FOR MEASUREMENT OF PALEOTEMPERATURES

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The abundance of the heavier isotopes of oxygen in calcium carbonate deposited under equilibrium conditions is greater than that in the water from which it is deposited by approximately 2.5 per cent

(calculated) and is slightly greater if deposited at low temperatures rather than high temperatures. Since isotopic solutions both solid and liquid are nearly ideal this makes possible the use of these abundances as a temperature measuring device. The necessary conditions are (1) that animals lay down calcium carbonate in equilibrium with water so far as the isotopes are concerned, (2) that this isotopic abundance is not disturbed after once laid down, (3) that the isotopic abundance can be measured with sufficient precision, *i.e.*, 0.018 per cent of the ratio for 1 degree C., and (4) if this is to be used for a paleothermometer, that the oceans have the same isotopic abundances today as in past geological ages. Since fresh waters have markedly different isotopic abundances from sea water only fully marine deposits can be used.

We have secured the necessary precision of analysis and have secured evidence that the belemnites of the Upper Cretaceous chalk of England have preserved their isotopic composition while the chalk itself and its fossil oysters have not. Further evidence in regard to the reliability of this thermometer will be presented. The temperatures of the English upper Cretaceous as measured vary from 17.5°C. to 26.5°C. with probable errors of about 1°C. so far as measurements of the isotopic abundances are concerned. Owing to difficulties in securing reliable temperature standards, the error may be somewhat larger.

DIFFERENTIAL EROSION ON SLOPES OF NORTHERN AND SOUTHERN EXPOSURE IN WESTERN WYOMING

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The type of vegetation on the steep slopes of ranges such as the Hoback and Gros Ventre depends largely on degree of insulation. Warm south-facing slopes have a cover of bunch grass; north-facing slopes are forested. This differential protection is held to be the main reason for the differences in pattern and rate of erosion on north-facing and south-facing slopes, especially in places where valleys and ridges run at right angles to bedrock control.

Forested north-facing slopes have retreated little since the last episode of downcutting by axial valley streams, and relatively straight fronts persist. South-facing slopes are generally furrowed by small water courses or deeply embayed by minor valleys; zones of south-facing slopes have receded to force divides well northward of the midpoints between axial valley streams. Valley-wall belts of south-facing slopes are broader than those facing north.

South-running tributaries have built alluvial fans which deflect axial-valley streams southward and cause them to nip and oversteepen the bases of north-facing slopes.

Gophers are restricted to south-facing slopes where their food of annual and perennial plants abounds; they bring to the surface large quantities of fines which rains sweep rapidly down the 30-degree slopes. Probably stock grazing on grassed slopes is now a contributing factor to differential erosion.

PENNSYLVANIAN ISOPACH STUDIES IN THE EASTERN AND CENTRAL UNITED STATES

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Isopach maps of divisions of the Pennsylvanian in the United States are presented based on study of regional variations in 700 counties east of the Permian basin and Rocky Mountains.

Springer strata correlated with Pocahontas, Parkwood, Stanley-Jackfork, and Tesnus are restricted to the Appalachian, Ouachita, and Marathon geosynclines and Anadarko and Ardmore basins, attaining maximum thicknesses of 12,000 feet in the Ouachitas of Oklahoma.

Morrowan strata extend farther west and north over the craton reaching 5000 feet in the Coosa Coal basin, Alabama.

Lampasan beds correlated approximately with Kanawha, lower Tradewater, lower Cherokee, Atoka, Smithwick-Big Saline, and Haymond are thick in geosynclines, 4000 feet in Virginia, 8000 feet in southeast Oklahoma, but wedge out northward and are absent in portions of many of the Central States.

Des Moines strata overlap most of the residual pre-Pennsylvanian highs and attain greater distribution than older groups. There is a maximum thickness of 7000 feet in the Ardmore basin.

Missourian strata are absent from most of the geosynclines and display smaller thickness variation. A maximum of 3500 feet is found in the Anadarko basin. These are the oldest Pennsylvanian beds on parts of the Nemaha Ridge and central Kansas uplift.

The Virgil has moderate thickness in the northern Appalachian area, is almost entirely eroded in the Eastern Interior basin, and is widespread in the Mid-continent attaining 2000 feet in the Anadarko basin. Virgil strata overlap pre-Pennsylvanian on the flanks of the Wichita Mountains and are overlapped by Permian beds higher in this range. (Geological Society project 498-46)

STATUS OF SCLERACTINIAN STUDIES

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The basic element for the classification of the Scleractinia or stony hexacorals—the structure of the septa—is now well established; the mode and trends of colony formation, of the greatest importance in generic discrimination, have been fairly well worked out and applied; and the great ecologic and individual variation of growth form is fairly notorious. The recognition of polyphylogeny and homeomorphy adds much complexity to the thorough analysis of the group and indicates the future line of research with large suites of material, once the preliminary descriptive and taxonomic phases of scleractinian study, now well under way, are in hand. Examples of the above points, based upon recent and fossil scleractinians, are given.

SYSTEMATIC DRAINAGE CHANGES IN THE PIEDMONT

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In the Piedmont of North Carolina and Virginia northeast-flowing tributaries of southeast-flowing rivers such as the Catawba, Yadkin, and James are long and subparallel. Opposing tributaries on the northeast sides of the main streams are short and irregular in direction. This asymmetry suggests the former existence of a subsequent drainage flowing northeastward toward the Potomac. Apparently it was dismembered by multiple captures effected by short southeast-flowing streams of steeper gradient.

The drainage area of this former stream system appears to be delimited by an enclosing zone of monadnocks on the southeast and southwest and by the Blue Ridge Scarp on the northwest. It is developed largely upon the granites and older metamorphic rocks, while the marginal monadnocks (Uwharrie Hills, etc.), which mark the former divide on the southeast, are developed largely on the Carolina slates. The zone of terminal monadnocks which marks the headwater divide extends across the strike, on the older metamorphic rocks approximately along the boundary between North Carolina and South Carolina.

Apparently a succession of captures progressed across the area as the stronger southeast-flowing

streams insinuated their headwaters northwestward, dismembering and diverting each of the northeast-flowing streams in turn, beginning at the southeast and ending at the foot of the Blue Ridge on the northwest. Elbows of capture are sharper in the northwestern streams where captures were later. There also, strath terraces are preserved across the divides between present major streams such as the Yadkin and Catawba.

Present stream profiles show lower gradients in the area of the former northeast-flowing drainage than in the slate belt to the East.

HELICOPRION-LIKE FOSSILS IN THE PHOSPHORIA FORMATION*

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The recent discovery of a very large example of a symphyseal whorl of teeth, tentatively identified as *Lissoprion ferrieri* Hay, in the shale member of the Phosphoria formation at the Simplot phosphate mine near Fort Hall, Idaho, recalls other occurrences of similar fossils in the Phosphoria.

Hay's announcement in 1907 of the discovery of specimens he described under the name *Lissoprion* was probably the first record of the presence in the Phosphoria of a shark closely related to *Helicoprion*. Hay's material was collected at localities near Montpelier, Idaho, and Thomas Fork, Wyo., from beds now included in the Phosphoria formation. In 1940, Marcus I. Goldman obtained an incomplete spiral of the same identity from beds assigned to the Phosphoria along Sheep Creek in the Uinta Mountains, Daggett County, Utah. In 1943, J. S. Williams and others collected a very incomplete specimen in Montpelier Canyon from the phosphatic shale member of the Phosphoria, and several additional discoveries were made during the 1948 field season. Another specimen, identified as *Helicoprion ferrieri* and of unknown derivation but probably from the Phosphoria, was reported by H. E. Wheeler in 1939 to be in the collections of Stanford University.

Other materials identified as *Helicoprion* have been found in Nevada and California, and closely related edestid sharks occur in late Paleozoic rocks at several places on other continents. These newly reported Phosphoria occurrences are of considerable interest, therefore, in connection with continuing stratigraphic and faunal studies of the formation started by J. S. Williams in 1936. Some stratigraphic sections of the Phosphoria are discussed with reference to occurrences of these edestids and their general age significance.

THE EARTH'S CRUST

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The crust is defined as the thin shell that lies above the Mohorovicic discontinuity under continents and is represented in Pacific areas by basalt. Its thickness varies from 30 to 50 kms., and it consists of igneous rocks and their derivatives. Basalts and granites predominate and determine the major structures. Both rocks rise molten from the solid mantle. Magma bodies may be compared to bubbles, pushed up by heavier plastic wall rock, aided by chemical and thermal activity of fluids and gases. Rising bubbles exert lifting force, expand and evolve gases; cooling they contract and lose gases; thus they cause uplift and subsidence.

The crust has been built up by intrusions penetrating along partings offering least resistance. When they encounter masses they find easier paths around them rather than through them. Since

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molten bodies tend to assume oval forms their peripheries are curves, and they occasion arcuate volcanic chains and mountain arcs. As magma pushes any segment up it produces deep-seated downdraft and subsidence in an adjacent zone, resulting in geosynclines and oceanic deeps. Among causes of orogenic pressures intrusion of viscous bodies of granite is important; so also is lubrication by fluid basic lavas.

Since peridotite if remelted may yield basalt and melting basalt may produce granite, that sequence is expectable. Confined radioactive heating may have been a cause of basalt intrusions, which, if still insulated with radioactive content, would on remelting yield granite.

The crust has accumulated. Its structure expresses growth. It is still growing from below.

LAURENTIAN MOUNTAINS OF LATE PRE-CAMBRIAN TIME

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A great fault zone is known to divide the rest of the Canadian Shield from the Grenville and Adirondack subprovinces, whose characteristics include folding and foliation generally parallel with the fault zone, and evidence, still fragmentary, of a belt of negative gravity anomalies. Grenville metamorphic rocks were apparently once normal geosynclinal sediments, whereas Huronian rocks north of the fault are of continental character. A great series of basic intrusives and associated base-metal deposits of late pre-Cambrian age follows the northern side of the fault. Radioactive age determinations south of the fault are less than 1100 million years, whereas those to the north are older.

A possible explanation is that Grenville sediments accumulated in a shelf geosyncline off a smaller primitive continent of Keewatin, Timiskaming, and Algoman rocks. About 1100 million years ago, it failed and was folded into mountains parallel with the St. Lawrence River. The roots were granitized and exposed as the present Grenville and Laurentian rocks, with residual negative gravity anomalies, but continued pressure caused fracturing into a frontal thrust and rift valleys and intrusion of basic rocks. Uplift and erosion provided material for marine deposits to the south and Huronian rocks on the continent to the north.

VERTEBRATE FAUNA OF A PERMIAN LOCALITY IN TAYLOR COUNTY, TEXAS

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A collection of Permain vertebrates from the Vale formation of the Middle Clear Fork near Lawn, Texas, is described. The material came from a small quarry at a single stratigraphic level. It is, therefore, believed that it represents as close to a natural assemblage as is possible to find.

The fauna contains complete paleoniscid fish, *Trimerorbachis*, *Seymouria*, and a large number of disassociated bones of *Dimetrodon gigashomogenes*. The *Dimetrodon* material includes many examples of immature individuals.

The geographic range of the Lower Permian vertebrate fauna of Texas is extended more than 100 miles to the southwest.

A large flora was collected from the same quarry. From the nature of the plants and the soft, gray, even-bedded shale, it is concluded that the sediments were deposited in a quiet fresh-water lake or in a sluggish river.

RELATIONSHIPS OF *PARADJIDAUMO* AND THE EOMYIDAE

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The Eomyidae comprise a group of late Eocene and Oligocene rodents common to both North America and Europe. *Protadjidaumo*, *Adjidaumo*, and *Paradjidaumo* are American members. Little doubt exists as to the necessity for establishing a distinct family for these genera although opinions as to the superfamilial relationship of the genera are strikingly diverse. A nearly complete skull of *Paradjidaumo*, and several additional skull fragments of the genus in the collections of the California Institute of Technology, permits a further attempt to determine the affiinities of the Eomyidae to other rodents. Results from the study are indecisive. The Eomyidae combine features of the Aplodontoidea, Geomyoidea, and Myomorpha. Resemblances to the Castoroidea, and particularly to the Sciuroidea, are distinctly less evident. If the zygomasseteric structure is a valid criterion for classification, the Eomyidea perhaps should be viewed as a relatively primitive group more nearly related to the geomyoids than to other rodents. The relationship however is not close.

WHAT IS A MINERAL?

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The old definition of a mineral as a natural inorganic substance of definite chemical composition is criticized, a new definition is proposed, and its effects are illustrated.

BLISTER HYPOTHESIS AND THE OROGENIC CYCLE

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A hypothesis is offered to account for the distribution of mountains in time and space. It is suggested that within a zone not more than 50 miles deep below the earth's surface, heat, primarily from radioactive disintegration, accumulates more rapidly than it can be dissipated, and a large convex upward lens of heated and expanded rock which is potentially liquid accumulates beneath the surface. This blister causes a doming of the overlying crust which may fracture and allow the escape of magma and heat with a subsequent partial collapse of the blister. Around the margin of the expanding blister the crust is subjected to tension; and a zone of weakness develops, which, if other factors are favorable, will develop into a geosyncline.

If at any time the accumulating heat escapes in the form of magma through the roof of the blister or laterally into the deepening geosyncline, gravity would cause the roof to settle down to a smaller arc which would be adequate force for crumpling the sediments of the geosyncline. Vast quantities of magma might be forcibly introduced into the sediments; and the room taken by the intruded rock would explain the extensive apparent crustal shortening which is one of the outstanding problems of mountain building. The development and collapse of blisters beneath continents and oceans, alike, would be cyclic. Oceanic blisters would produce a rhythmic rise and fall of sea level. The known facts of orogenesis, epeirogenesis, distribution of continents and ocean basins, the petrogenic cycle, and regional metamorphism are unified into one coherent picture through this hypothesis.

BIRD MIGRATION AND THE CONCEPT OF CONTINENTAL DRIFT

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A recent, critical study and analysis of the problems of bird migration in relation to continental drift has led to the conclusion that continental drift was the stimulus for the evolution of the more highly developed forms of migration. In essence, this hypothesis holds that the birds that responded to the movements of the continents, as they drifted apart and moved northward and/or followed the development of the new oceans created by drifting land masses, belong to those species which at present exhibit migration in its most highly developed form. The premises on which the hypothesis is based are that: (1) birds originated in the Southern Hemisphere, (2) the inherent behavior of moving to and from nesting and feeding grounds had appeared soon after the origin of birds, (3) many birds returned to the same feeding and nesting areas even though they became divergent, and (4) only those individuals survived as migrants that developed the necessary sources of energy to enable them to complete the flight between the diverging areas.

That drifting played an important role in the evolution of migration seems attested by the extent, direction, and general pattern of migration and the correlation of these features with the evolution of the continental masses from the standpoint of continental drift. That the establishment of energy resources played an important role in the evolution of migration is attested by the correlation of fat deposition and migratory behavior under natural as well as experimental conditions.

THERMAL STUDY OF RHODOCHROSITE

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Representative specimens of rhodochrosite from many localities have been examined by differential thermal analysis in order to establish the form and variations of the thermal curve of the mineral, and to study the effect of cation substitition on its thermal behavior. The optimum conditions of sample and apparatus providing reproducible thermal curves for this mineral group are discussed.

The endothermic peak was found to reproduce more consistently than the exothermic, varying from 609° C. to 724° C., but only one specimen gave an endothermic peak higher than 667° C. The majority range from 609° C. to 635° C. The temperature at which the endothermic peak occurs is raised by the presence of Ca and Mg and is lowered if iron substitutes for manganese in the lattice.

The materials used in the thermal work were checked by powder x-ray patterns and semiquantitative tests for the cations in question.

Several specimens of manganocalcite varying widely in manganese content indicate that the substitution of Mn for Ca in the series calcite-rhodochrosite is probably continuous and unlimited.

ACTIVITY MEASUREMENTS OF MICRORADIOACTIVE INCLUSIONS

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The activity of minute radioactive segregates in polished sections of rocks or microincinerated biological tissue is determined by counting alpha particle tracks recorded in nuclear type emulsions.

Precise localization of particular segregates whose area exceeds 10^{-4}cm^2 is established by a double-exposure technique. The track count affords, in certain instances, an approximate measure of either the U or Th content. Applications of the method in the study of segregates in feldspar, beryl, and other minerals associated with radioactive ores will be described.

ABSTRACTS OF PAPERS PRESENTED AT MEETING IN PASADENA, APRIL 9–10, 1948

CORDILLERAN SECTION OF THE GEOLOGICAL SOCIETY OF AMERICA

HISTORICAL SIGNIFICANCE OF DESERT LACQUER

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Rock surfaces in warm deserts slowly acquire a thin brown coating of iron and manganese oxides, which is often called "desert varnish" or "patina." It is characteristic of rock outcrops and upland gravel not subject to modern floods or the sandblast. Its absence on such rocks as limestone is due to the more rapid wastage of those materials by solution.

The genetic hypotheses of Walther, Lowdermilk, White, and others, ascribing desert lacquer to both inorganic and biochemical processes, will be reviewed.

Studies in the desert region of southeastern United States and in Egypt indicate that the coating forms so slowly that a geologic epoch, rather than centuries, is required for full development. Among the significant facts are its relations to the shore lines of desert lakes, to terraces of known geologic age, and similar features. In Egypt, where ancient monuments abound, the formation of desert lacquer in the last 2000 years has been scarcely perceptible, only slight in 5000 years, and has reached full development only since Paleolithic time. It thus becomes helpful in estimating the relative ages of rock and gravel surfaces.

Ordinary desert lacquer should be distinguished from "river film," which blackens the rocks along the cataracts of the Nile. While the two varieties are evidently related in origin, river film forms much more rapidly and is not limited to deserts, being found in the valley of the Orinoco, the Congo, and other tropical rivers.

MOVEMENT ON THE MANIX (CALIFORNIA) FAULT ON APRIL 10, 1947

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During an earthquake on this date the Manix fault developed a surface trace 2–3 miles in length. This is one of the half dozen known cases of fault displacement cutting the land surface that have occurred on California faults within historic times. The Manix fault trends east-west along the Mohave River about 2 miles south of Manix and Field, stations on the Union Pacific Railroad about 30 miles east of Barstow. The displacement along the surface trace of the fault was only 1–2 inches and scarcely discernible by offset of drainage features. The movement was left hand in nature; the south side of the fault moved eastward relative to the north side, as in the case of the Garlock fault 50 miles to the north. This rupture on the Manix fault occurred in a zone of fracturing described by the senior author in 1913 as cutting Quaternary beds. Displacements in this zone some miles to the east apparently created the depression in which the Mohave River was confined and in which it cut Afton Canyon.

PLIOCENE FLORA FROM THE RATTLESNAKE FORMATION OF OREGON

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Fossil floras from Eocene, Oligocene, and Miocene deposits in the John Day Basin have provided one of the most complete sequences of Tertiary forests on the continent, although records of Pliocene

vegetation have been limited to adjacent valleys of the Deschutes and Columbia rivers. During the summer of 1947, a field class from Oregon State College under the leadership of W. D. Wilkinson made the first discovery of plant fossils in the Rattlesnake formation, near Dayville. A small collection which I made later in the season contains leaves of *Platanus*, *Ulmus*, *Salix*, and other genera regularly found associated in deposits of Middle Pliocene age.

TERRACES ON SANTA CATALINA ISLAND, CALIFORNIA

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The question of whether or not Santa Catalina Island shows evidence of terracing has been a controversial one for many years. Lack of adequate topographic maps of the island has been one factor that has delayed settling of the question to the satisfaction of all concerned. During World War II the U. S. Army Engineers made a topographic map of the island on a scale of 1:25,000, with a contour interval of 50 feet. Profiles made from this map suggest the presence of terraces.

BURIED CHANNELS AND THEIR RELATION TO DAM SITES ALONG THE COWLITZ RIVER, WASHINGTON

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The Cowlitz River drains the western slope of the Cascade Mountains in Washington. From its source in the glaciers on the southern slope of Mt. Rainier, the Cowlitz River extends 120 miles to Kelso, Washington, where it empties into the Columbia River.

During the Pleistocene, alpine glaciers advanced down this valley two, or possibly three, times. In contrast to all the valley glaciers farther north, which Mackin has shown were blocked by the Puget Sound continental ice, this valley was open at the lower end. At the time of maximum advance, the Cowlitz Glacier was 70 miles long. As a result of repeated ice occupancy, the course of the river has been diverted many times resulting in a complex system of channels now filled or partly filled, with till, silt, outwash, and alluvium.

The City of Tacoma Department of Lighting is now investigating the suitability of several dam sites along the Cowlitz River near the town of Mossyrock. Drilling, started early in 1948, is giving pertinent data concerning the depth, width, and character of fill in the buried channels adjacent to the dam sites. This information, together with the geology of the reservoirs, will determine, in large measure, the suitability, location, and height of the proposed dams.

TERTIARY (?) INTRUSIVES IN THE HESSIE-TOLLAND AREA, BOULDER AND GILPIN COUNTIES, COLORADO

ALLAN CREE

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In the Hessie-Tolland area of the Colorado Front Range, the Bryan Mountain stock and associated dikes are Tertiary (?) discordant intrusions into the complex pre-Cambrian Idaho Springs formation.

They were emplaced chiefly by piecemeal stoping. Within the eroded stock, the results of the stoping processes are abundantly exposed in the form of contact-zone breccia and partially dissolved xenoliths. The attitude of flow structures implies that the contacts of the stock with the country rock are almost vertical.

The rocks of the stock and dikes range from andesite to granite. Field relationships and thin section analyses suggest that the parent magma was dioritic. During emplacement, an orderly change in composition from diorite through syenodiorite to monzonite is indicated. At the same time, a subparallel series of quartz-bearing syntectic rocks was formed by assimilation of the pre-Cambrian country rocks. This latter series ranges from tonalite through granodiorite to adamellite. The youngest intrusive rocks of the area are dikes of granite and aplite.

Established usage implies that many similar igneous bodies in the Front Range are of late Laramide age. All intrusives in the Hessie-Tolland area are, therefore, arbitrarily referred to early Tertiary.

PRE-CAMBRIAN STRATIGRAPHY AND STRUCTURE OF THE MINGUS MOUNTAIN QUADRANGLE, ARIZONA*

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The pre-Cambrian Yavapai schist of the Mingus Mountain quadrangle is bounded by normal faults of Tertiary age. The Yavapai is divided into two parts, an eastern and a western part, each consisting of tuffaceous metasediments and interbedded flows.

The western part contains four known mappable units (interbedded metarhyolite tuffs and purple slates locally containing meta-andesite flows, metarhyolite tuffs, meta-andesite tuffs and flows, and intercalated metarhyolite and meta-andesite flows). In this part foliation is slightly discordant to bedding. Lineation is common and plunges, in general, steeply southward; it has not been related to any major structure. Folding is limited to isoclinal folds of small amplitude, but strike faults are common and of considerable magnitude.

In chronological sequence the eastern part consists of meta-andesite flows; metarhyolite flows and breccias; interbedded cherty sediments, lithic tuffs, and metadacite flows; and meta-andesite breccias. The dominant structures are open folds, striking north-northwest and plunging, in general, southward. North-northeast- and east-striking faults of moderate displacement are common on the eastern side of the area.

A major fault separates the eastern from the western part and renders determination of age relations impossible. It truncates the foliation of the western part and the folds of the eastern.

The Yavapai schist is intruded by a large mass of granodiorite and smaller masses ranging from quartz porphyry to gabbro. The igneous rocks associated with the western part are foliated, whereas hose associated with the eastern part are massive.

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BIG PINE FAULT, CALIFORNIA

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The Big Pine fault extends east-northeastward to the San Andreas rift. This extended portion exhibits *left lateral* offset (sidewise, with block opposite the observer relatively shifted to the left). Offset of canyons indicates *strike-slip* movement, and offset of structures and contact suggests 8 miles of *left lateral* displacement. The Garlock fault, also *left lateral* and trending east-northeastward, abuts the San Andreas 3 miles east of the junction of the Big Pine with the San Andreas.

Since the San Andreas is a *right lateral* fault, it is suggested that the Garlock and Big Pine were formerly continuous. Furthermore, it is suggested that *left lateral* displacement on the Big Pine-Garlock fault may be responsible for the east-west trend of the San Andreas in this vicinity. Finally, it is suggested that the 600-mile, northwest-trending, *right lateral* San Andreas and the 200-mile, east-northeast-trending, *left lateral* Big Pine-Garlock fault may be genetically related elements of a major *strike-slip* shear system. This *strain* system would appear to involve crustal shortening in a north-northeast, south-southwest orientation.

Much remains to be learned about these faults, the associated structures, and the geologic history of this extensive region. However, a preliminary analysis suggests that this area has been deformed by a stress couple which was compressive north-south and clockwise rotational.

POSSIBLE JURASSIC AGE OF MUCH OF THE "CALAVERAS FORMATION", CALIFORNIA*

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The Calaveras formation was originally defined by Turner to include all the Paleozoic sedimentary rocks of the Sierra Nevada. Shortly thereafter he excluded Silurian and upper Carboniferous strata

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and stated that the Calaveras is chiefly lower Carboniferous but may include the Devonian. Knopf thought part of the formation might be Triassic. Recently, Taliaferro has separated a Jurassic unit, west of the Mother Lode, from rocks previously mapped as Calaveras formation.

The rocks east of the Mother Lode region have been mapped previously as Calaveras formation because they are more schistose ("more metamorphosed") than the Jurassic rocks to the west, and because they contain small limestone lenses in which Paleozoic fossils are found. Present work along the Mother Lode in southern Calaveras and northern Tuolumne counties shows, however, that most, if not all, small limestone lenses occur in fault zones and are in fault contact with the majority of "associated" noncalcareous rocks. Presence of small limestone lenses has been effectively used as a criterion for faulting. Lithologic similarity, discounting the effects of slightly increased thermal metamorphism and greatly increased shearing, suggests that large areas previously mapped as Calaveras formation actually may be Taliaferro's Amador group of Jurassic age.

Rocks associated with the large limestone lens at Columbia have not been studied in detail but seem to be dissimilar to the Amador group and may be Paleozoic.

SPHEROIDAL STRUCTURES IN ARIZONA VOLCANICS

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Occurrence of spheroidal forms in a flow of red rhyolite and in a devitrified tuff is described from the Canelo Hills, Arizona. The rhyolite outcrop has been traced for approximately a mile, the flow averaging 20–25 feet thick. The spheroidal forms, ranging from a fraction of an inch to 12 inches in diameter, constitute 50–75 per cent of the weathered surface throughout its entire content. Flow structure, apparently continuous from matrix through the spheroids, is clearly displayed.

The gray spheroids have been found in an area measuring about 800 by 200 yards, and about 100 feet lower in the stratigraphic sequence than the rhyolite. They are less abundant and less prominent on the outcrop than the rhyolite structures, but occur commonly free from matrix in the talus. All have cores, most of which are tessellated calcite.

Thin sections were prepared to encompass entire equatorial cross sections of individual spheroids.

Under the microscope occasional spherulites are found within the larger rhyolite spheroids. Well-developed flow structure is characteristic. Both primary and secondary quartz is abundant. There is no radial or concentric mineral orientation.

The gray tuff shows heavy concentrations of secondary calcite, other than that in the cores, impartially distributed in matrix and spheroid.

The absence of demonstrable secondary control of the rhyolite spheroids suggests that the structure is primary.

FUSION OF LACUSTRINE DEPOSITS NEAR VERDI, NEVADA

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A series of lacustrine strata, commonly referred to as the Truckee formation, occurs in the vicinity of Verdi, Nevada. The material is largely pyroclastic. The sediments are unconformably overlain by lava flows clearly indicating a post-Truckee period of volcanism.

A short distance north of the Truckee River the sediments are cut by a series of east-west fractures along which the rock has been changed into a slaggy, clinkery, and scoriaceous mass. Occasionally small quantities of the rock became sufficiently fluid to flow. Large masses of the sediments have been baked and changed from their original light buff to a deep red. Baking, and partial fusion, of the sediments immediately adjacent to fractures suggests that the latter served as channelways for heated gases. Probably the heated gases were related to the period of late volcanism.

CEMENTATION OF SOME CALIFORNIA TERTIARY SANDSTONES

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Forty core samples of feldspathic sandstone from wells in southern California have been studied in thin section using a universal stage. Secondary (authigenic) minerals deposited in open pores or formed within a clay matrix include quartz, albite, orthoclase, microcline, dolomite, calcite, anatase, pyrite, coarse clay (kaolinite?), and barite. These minerals together with the primary clay matrix prominent in some rocks are the cementing substances.

Secondary quartz occurs as crystallographically continuous outgrowths on detrital grains. The secondary feldspars are both outgrowths on detrital feldspar and euhedral authigenic crystals in cavities. Dolomite takes the form of small rhombs and is most abundant in clay matrix, whereas calcite is typically an anhedral cement filling open pores. Kaolinite (?) occurs as radial fibrous aggregates or large single grains in the clay matrix. Secondary feldspars and dolomite have idiomorphic outlines in contact with secondary quartz and calcite. In many instances calcite has grown on top of secondary idiomorphic quartz.

In the present suite of sandstones, both porosity and permeability tend to be less in those rocks cemented by quartz, feldspar, or calcite than in those cemented by clay.

Grain-on-grain pressure and consequent solution at points of contact between grains is a possible explanation for intricately penetrating contacts between detrital grains of quartz and feldspar. The crystallization of secondary quartz and feldspar may well be complementary to such local solution.

REPLACEMENT AND RHEOMORPHIC DIKES

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Many small dikes ranging from diorites to aplites show numerous field features which indicate that they were formed by replacement rather than by the dilation of a fissure followed by magmatic injection. These criteria include: lack of offset on transecting an earlier dike at an angle, bridgelike septa of country rock across the dike, an irregular form with a tendency toward lenticularity and both sharp and gradational borders. In thin section crystalloblastic textures and structures prevail, and there is complete lack of flow structure or chilled borders or increase in grain size from the walls inward. However, the most cogent evidence of replacement is furnished by dikes in various stages of development from initial parallel mineralized fractures to fully formed dikes.

The writer has recently studied similar dikes at Cornucopia, Oregon, which exhibit some of the field and petrographic features of replacement dikes. Their "phenocrysts" suggest an earlier porphyroblastic origin, but a marked flow structure indicates a mass movement. These conflicting data are interpreted as follows: A continuance of more active emanations following passive metasomatic replacement causes the newly formed material to flow as a neomagma and form a rheomorphic dike.

AREAL GEOLOGY OF PART OF THE SOUTHERN CALIFORNIA PEGMATITE BELT*

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The areal geology of a belt covering about 150 square miles in Riverside and San Diego counties is being mapped by the U. S. Geological Survey to establish a background for detailed studies of the Pala, Rincon, and Mesa Grande pegmatite districts. The area is within the batholith of Southern California. The rocks mapped range from Triassic (?) to Pleistocene, although exact dating of all the rock units is not possible.

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The oldest rock unit exposed is the quartzite and schist series of the Triassic (?) Julian formation. This formation has been intruded by the Stonewall quartz diorite, tentatively dated as Jurassic, in the eastern part of the belt. These pre-batholithic rock units have been intruded throughout the belt by the batholithic sequence that ranges from San Marcos gabbro through the Green Valley, Bonsall, and Lakeview tonalites to the Woodson granodiorite, and in age from Jurassic (?) to Middle Cretaceous. All the rock units have been intruded by pegmatites and aplites. The youngest rocks, which occur only in the western part of the belt, are semiconsolidated, Pleistocene fanglomerates and arkoses.

The Elsinore fault zone, which has been mapped in considerable detail for a length of 24 miles, is the major structure of the belt and appears to be localized along older sructures.

Preliminary results indicate that the localization of the pegmatite districts is controlled by a combination of (1) favorable structures that may have been caused by movement in the fault zone, and (2) favorable host rocks.

UPPER JURASSIC STRATIGRAPHY OF BLOCK MESA, ARIZONA*

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The Upper Jurassic formations in Black Mesa, northern Navajo Indian Reservation, Arizona, lie in a broad gentle syncline and were formerly referred to as the McElmo formation. They are, in ascending order: (1) Carmel formation, (2) Entrada sandstone, and (3) Morrison formation. This interpretation is based upon both lithology and stratigraphic position.

The Carmel formation consisting of alternate beds of gray sandstone and red, sandy shales is separated from the underlying Navajo sandstone by an unconformity.

The Entrada sandstone, next higher formation, consists of massive, red, cross-bedded sandstone. It is gradational into both the underlying Carmel formation and the overlying Morrison formation.

The Morrison formation, 650 to 250 feet thick, contains four well-defined members. These are, in ascending order: (1) massive, pale-green, cross-bedded sandstone, (2) gray, poorly sorted sandstone and irregular, granule lenses, (3) alternate beds of gray, poorly cemented sandstone and maroon, sandy shales, (4) thin-bedded, brown sandstone and minor lenses of reddish, sandy shales. An erosional unconformity separates the Morrison formation from the overlying Dakota sandstone of Cretaceous age. Lateral and vertical variations of the Morrison members are discussed.

Mechanical analyses, studies of thin sections, and sedimentary structures are being used to determine: (1) source of sediments, (2) agents of transportation, (3) agents of deposition, and (4) environment of the region during Upper Jurassic time.

LATER CENOZOIC AVIAN FOSSILS FROM NEAR NEWPORT BAY, ORANGE COUNTY, CALIFORNIA

HILDEGARDE HOWARD

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Two avian fossil localities have been discovered in the mesas east of Newport Bay, Orange County, California.

The earliest of these, geologically, is 1¼ miles east of the upper end of the bay. Here 14 bird bones were found in dipping Pliocene sands. Two species of extinct birds were identified, one of which is referred to the flightless auklike bird, *Mancalla*, originally described from the Third Street Tunnel excavation in Los Angeles and more recently recorded from the San Diego Pliocene.

The second deposit is of Upper Pleistocene age and is located about 1 mile to the west. Here 50 avian specimens representing 15 species have been recovered. This assemblage rivals that from the Lumber Yard at San Pedro (also Upper Pleistocene) in importance of material represented. Three extinct species occur at Newport, and only one at San Pedro. As all three of the extinct species are of marine types their absence at San Pedro is presumably attributable to habitat rather than age. In

* Study made under a fellowship granted by the Shell Fellowship Committee.

all respects the essential differences between the two assemblages may be accounted for by the fact that the Newport fauna is more strictly marine and is in this respect closer to that of the Playa del Rey deposits.

TRANSMISSION OF STRESS THROUGH ICE FOLDS OF THE BAY OF WALES, ANTARCTICA*

ARTHUR DAVID HOWARD

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The Ross Sea is blanketed by a sheet of ice hundreds of feet thick. The sheet terminates in a high ice cliff, the Ross Barrier. The Bay of Wales is a 15-mile re-entrant in the Barrier. The walls of ice are closing in on the bay and crushing the sea ice between them into miniature fold mountains.

In 1947, the belt of folds varied in width from a few hundred yards to more than a mile, and individual anticlines approximated 150 feet in height. The broader parts of the belt were characterized by relatively low, open folds. In the absence of a "basement complex," the problem of transmission of stress through the open, crevassed folds presented itself.

A minimum thickness of 80 feet of ice was observed in the core of one anticline. The total thickness may have been much greater. Reasons are given for the belief that the ice could not have been so thick prior to folding. It seems probable that, as an anticline rises, the sea water in the core freezes, forming a filling. The base of this filling extends below sea level, and its compactness depends on the rate of uplift. At the same time, sea water invades the subsiding synclinal troughs and freezes to form thickening synclinal fillings, the upper surface of which is at or above sea level. It is suggested that these solid anticlinal and synclinal fillings permit the transmission of the horizontal stresses directly across the folds, rather than around the convolutions of the flexed ice strata.

MEASUREMENT OF DEFORMATION OF SIERRA NEVADA SINCE MIDDLE EOCENE

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The main channel of the middle Eocene Yuba River is known from its mouth, a short distance east of the western edge of the Sierra Nevada, to the present range crest, immediately northwest of Donner Pass. Abrupt changes of gradient between variously directed reaches of this channel led Lindgren to conclude that the range had been tilted 60 feet per mile W.-SW., as a rigid block. Believing the faults east of the crest insufficient to account for such increase of slope, he proposed a composite movement: uplift of an area greater than the present range, with local sinking of moats. A corollary, not stated by him, is that both moats and mountains suffered absolute uplift.

Lindgren underestimated the faulting east of the crest. It is probably adequate to account for the 3300 feet of crustal uplift caused by simple tilt of 60 feet per mile. But a study of his basic data, and new data on the lower and upper reaches of the channel, shows that the uplift at the present crest was only 1838 feet. This is less than the sum of offsets on faults east of the summit. Accordingly the deeper grabens of that region must have suffered absolute depression since middle Eocene.

The uplift of the crest is not due to simple tilt of a rigid block. There are zones of deformation within the western slope, the principal one lying about midway between the summit and western edge of the range.

STILPNOMELANE AND PUMPELLYITE, CONSTITUENTS OF THE FRANCISCAN SERIES

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The deep red-brown micaceous mineral stilpnomelane has been observed as a constituent of some glaucophane schists in the Almaden area, and for it refractive index determinations (α = 1.599,

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$\gamma = 1.680$, $\gamma - \alpha = 0.081$) indicate a composition approximately midway between the ferrous and ferric end members of the stilpnomelane group.

Attention is drawn to the occurrence of this mineral since in some instances it has been wrongly diagnosed as biotite, with resultant incorrect plotting of isogradic boundaries.

The hydrous calcium aluminum silicate pumpellyite has been recognized as a constituent of slightly metamorphosed quartzo-feldspathic rocks of the Franciscan Series from Belmont, California. This mineral appears to be restricted to those rocks characteristic of the lower subzones of the Chlorite zone.

OBSERVATIONS OF NEAR-SHORE SAND TRANSPORT BY WAVES AT SCRIPPS INSTITUTION OF OCEANOGRAPHY, LA JOLLA

D. L. INMAN

It is known that ocean waves are effective in causing sand to be transported laterally along beaches by longshore currents and that there are both periodic and nonperiodic movements of sand from the foreshore to deeper water and back again to the foreshore. The study of sand transport is a boundary layer problem in hydrodynamics, and the mechanics of transport are not well understood.

Observations have been made with a sediment trap designed to catch sand in four cardinal directions and at elevations varying from 3 inches to 4 feet above the bottom. An attempt has been made to correlate these observations with present theories of sand movement based on a statistical analysis of wave conditions and observed currents. Total sand trapped may be written as a power function of the maximum orbital velocity as computed from the Airy wave theory.

MASSES OF PEGMATITE QUARTZ

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Masses of coarse quartz form parts of many pegmatite bodies. Most have been described as cores, pods, or ribs at or near the centers of such bodies, but other types have been recorded.

The well-exposed masses of quartz in the pegmatite areas of northern New Mexico and western Arizona can be classified as (1) single or segmented cores of pegmatite bodies, (2) intermediate zones of pegmatite bodies, (3) pods irregularly distributed within pegmatite bodies, (4) apophyses from larger quartz masses, or (5) vein-, plug-, and podlike masses in country rock. Some quartz masses flanked by granite, schist, or other rocks can be traced along their strike into cores or intermediate zones of pegmatite. Others, with like texture, structure, and mineralogy, are enclosed by nonpegmatitic rocks.

Associated with the quartz are perthite, albite, muscovite, epidote, beryl, hematite, ilmenite, magnetite, chalcocite, and other copper minerals, molybdenite, and very small quantities of bismuth minerals, chlorite, columbium-tantalum minerals, fluorite, pyrite, and rare-earth minerals. Muscovite, albite, and perthite form impregnations in the nonpegmatitic wall rocks.

Most of the quartz masses antedate the hydrothermal mineralization in near-by or enclosing feldspathic pegmatite and appear to represent the last part of an earlier, perhaps magmatic stage. Temperatures of formation probably did not exceed 300°C., but a magmalike liquid rich in SiO_2 could exist at such temperatures, provided substantial proportions of alkalis were present. This is suggested by physico-chemical data.

UPPER PLEISTOCENE INVERTEBRATE FAUNA FROM THE NEWPORT BAY MESA, ORANGE COUNTY, CALIFORNIA

GEORGE P. KANAKOFF

Los Angeles County Museum, Los Angeles, Calif.

Terrace deposits south of Newport Bay have yielded an invertebrate fauna of approximately 327 species, mostly Mollusca. Twenty-eight species are typical of the Panamic zone. At least 12

species are considered extinct. With the fauna are found some skeletal remains of birds and mammals. The assemblage is compared with the Upper Pleistocene Palos Verdes from San Pedro Hills and with that from Playa del Rey.

CORRELATION OF PLEISTOCENE LAKE TERRACES AND MORAINES AT MONO LAKE, CALIFORNIA

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Pleistocene lake terraces and moraines contact each other only at two places in the Great Basin—at the foot of the Wasatch Mountains south of Salt Lake City, and on the west side of Mono Lake. The dating of the lake terraces through correlation with the adjoining moraines has remained rather uncertain in both localities. New morphologic evidence on Leevining Creek indicates that Mono Lake reached its highest level during the Tahoe glacial stage and that the lake stood 250 feet lower during the Tioga glacial stage. The conspicuous lake terrace 650 feet above present Mono Lake which marks the most prolonged stay of the extended Mono Lake of the Pleistocene period occupies an intermediate position between these two levels and was carved some time after the Tahoe stage of glaciation. A Tazewell age is tentatively ascribed to this conspicuous terrace.

MAMMALS FROM THE PALOS VERDES PLEISTOCENE

JOHN P. LANCE

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The occurrence of scattered mammalian remains in the Palos Verdes sands of the Newport Bay Mesa has led to a study of available fossil materials from this horizon in Los Angeles and Orange counties, California, to determine the relationship of this faunal stage to that from Rancho La Brea. A survey of the entire assemblage leads to the conclusion that, while the Palos Verdes has some species in common with Rancho La Brea, it differs in the presence of *Tanupolama*, in apparent absence of mylodont sloths, and in the relatively frequent occurrence of tapir.

PETROGRAPHY OF THE ISLAND OF KAUAI, HAWAIIAN ISLANDS*

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Kauai is a volcanic doublet, composed of two dissected shield volcanoes partly inundated by much later eruptions. The larger shield, which rises 5170 feet above sea level, is built principally of olivine basalt, interbedded with which are lesser amounts of basalt poor in olivine, and picrite-basalt of the oceanite type rich in phenocrysts of olivine. A few of the basaltic flows contain a little hypersthene; and a few of the latest flows are andesine andesite. The smaller shield lies on the southeastern flank of the major shield and is much more deeply dissected. Its lavas are similar to those of the larger shield, except that andesites have not been found.

Following a long period of erosion a series of lavas and cinder cones (Koloa volcanic series) was erupted. The rocks include olivine basalt, "linosaite", picrite-basalt of the mimosite type containing few and small phenocrysts, "ankaratrite", nepheline basanite, nepheline basalt, melilite-nepheline basalt, and analcite basanite. Dunite inclusions are abundant. A table of chemical analyses of Koloa lavas is presented. One of the analyzed lavas, a melilite-nepheline basalt, contains only 35.84 per cent silica, less than any other analyzed lava from Hawaii.

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NEW CLARENDONIAN FAUNA FROM NORTHEASTERN NEVADA

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The Chalk Spring's fauna occurs in a series of tuffaceous sediments 15 miles south of Contact in Elko County, Nevada. These sediments are at the top of the Humbolt formation, and the fauna indicates that this formation extends up into Clarendonian time. Mammalian remains were found in 10 scattered localities within this area.

The following animals have been identified: *Hypolagus, Eucastor leconteí, Peromyscus antiquus*, a large new mustelid, an unidentifiable mastodon, *Neohipparion, Pliohippus, Aphelops, Teleoceras*, a new camel which appears to be related to *Alticamelus alexandrae*, a series of unidentifiable camelid remains, an antilocaprid, and an oreodont.

The available evidence indicates that this fauna is about equivalent in age to the Black Hawk Ranch fauna.

POSSIBLE SUN-SPOT CYCLE IN PRE-WISCONSIN VARVES IN THE PUGET AREA, WASHINGTON

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In the central part of the Puget Lowland, till of Wisconsin age veneers drumloidal hills cored by pre-Wisconsin glacial and interglacial sediments. The pre-Wisconsin succession is complex and, in general, poorly exposed. One of the stratigraphic units includes, from the base upward, till, varved clay, and nonvarved, peat-bearing clay and silt. Pollen studies by Hansen establish a forest succession indicative of warming climate during the period of deposition of the uppermost member. The stratigraphic unit as a whole was formed during recession of a pre-Wisconsin, probably early Pleistocene, glacier.

The varved clay is about 140 feet thick and includes about 470 paired summer and winter layers. Twenty to 30 sandy basal varves are so greatly disturbed by flowage contemporaneous with deposition that accurate measurements are impossible. The remainder of the sequence is characterized by sharp definition of the annual layers. The varves show a cyclic variation in thickness; groups of thick varves are two to three times as thick as overlying and underlying groups of thin varves. Intervals between maxima (or minima) range from 7 to 15 years and average 10½ to 11 years depending on interpretation of doubtful cases. The variation in thickness probably corresponds with variation in rate of ice wastage and is tentatively regarded as a reflection of the (approximately) 11-year sun-spot cycle.

USEFUL METHOD FOR DETERMINING APPROXIMATE COMPOSITION OF FINE-GRAINED IGNEOUS ROCKS

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The refractive indices of glasses formed by the artificial fusion of samples from a suite of calc-alkaline volcanic rocks from southern British Columbia show a close correlation with chemical composition. This relationship provides a rapid method of establishing the approximate chemical composition of other rocks from the same suite for which no analyses are available. Similar but not identical relationships can be expected for the igneous rocks of other suites and petrographic provinces.

MACROTURBULENCE IN STREAM FLOW AND ITS ROLE IN CHANNEL EROSION

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G. K. Gilbert defined corrasion as consisting primarily of mechanical wear and secondarily of solution. Mechanical wear of the stream bed he conceived to be effected by attrition and impact, processes requiring the presence of a sedimentary load. Streams of clear water, he asserted, corrade by solution only. More recently it has been recognized that channel erosion is effected in part also by plucking; but the precise manner in which streams pluck blocks from their beds is as yet imperfectly understood.

Large-scale turbulence such as Gerard H. Matthes reports on the basis of direct observation appears to furnish an important clue. He lists several types of vortex movement involving large masses of water and developing intense concentration of kinetic energy. Some of these powerful vortices suck material up from the bed and lift it spirally upward; others tear at projections of the channel walls. A major part of channel erosion thus appears to be effected by spasmodic tornadic whirls

The present writer's studies of the sculpture of channels eroded in different types of rock tend to confirm this conclusion. In jointed rocks plucking unquestionably is the dominant process. The tearing out of large blocks from bed and side walls, however, calls for more force than water flowing straight over or past them can exert. But the torsional effect of swiftly rotating water masses can readily provide the necessary power. Convincing evidence was found notably at the Great Falls of the Potomac and in the gorge below them.

PLAYA SCRAPERS AND FURROWS ON THE RACETRACK PLAYA, INYO COUNTY, CALIFORNIA*

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Shallow playa furrows, each ending at a rock fragment or low pile of dried mud, were observed on the Racetrack playa in the Ubehebe Peak area (Ballarat quadrangle). No precise measurements have been made. In general the playa scraper was a cobble-sized rock fragment as much as a foot in diameter and 6 or 8 inches high; or an inconspicuous low broad pile of fine-grained sediment; one was a machine-gun shell. The playa furrows were from several inches to several feet wide, from a few feet to well over 100 feet long, very shallow, and usually in a zig-zag. The width of a furrow was the same as the width of the scraper, and the depth roughly proportional to the weight per unit of surface on the base of the scraper. Most were several hundred feet from the rim of the playa. They were observed late in spring, after evaporation of shallow water that had remained during the winter.

A correct interpretation of how the cobble-sized fragments were isolated on an extensive bed of very fine-grained sediment may aid in understanding a similar occurrence in an old playa deposit. It is proposed that the scrapers were propelled over the muddy surface of the playa, initially from the rim, by strong gusts of wind blowing consecutively from different directions, such as the erratic whirlwinds that commonly produce dust-devils.

STRATIGRAPHIC FEATURES OF THE MOENKOPI FORMATION

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The Moenkopi formation at its type locality on the Little Colorado River, Arizona, consists largely of red claystones and siltstones, light-colored siltstones and sandstones, and gypsum, totaling less than 500 feet in thickness. These deposits have long been considered of early Triassic age on the basis of (1) stratigraphic position, unconformably above Permian marine beds and unconformably

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below continental Upper Triassic beds, and (2) correlation with thick deposits in southwestern Utah, some of which contain diagnostic marine fossils. Recently this age determination has been confirmed through the discovery by Dr. Sam Welles of a considerable Lower Triassic vertebrate fauna in the area of the type locality.

In view of the recent fossil discoveries an attempt is being made to demonstrate through sedimentary stratigraphic means the relationship of these bone-carrying beds in Arizona to the units with marine invertebrates in Utah. A series of carefully selected sections extending from near Zion Canyon, Utah, to the vicinity of Holbrook, Arizona, is being studied in detail. Five well-defined members are recognized in the western sections, with a total thickness of about 2000 feet. These are being traced eastward to the Little Colorado region, where the formation's thickness is only a few hundred feet. The decrease may be due to (1) lack of deposition of the lower units landward, (2) thinning of all units in that direction, or (3) lack of upper units either because of erosion or nondeposition toward the east. Evidences for and against each of these theories are presented and discussed.

CLASSIFICATION AND INTERPRETATION OF CROSS-LAMINATION

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Cross-lamnation is one of the most conspicuous and most diagnostic features of many sedimentary rocks. It is an indicator of the environment of deposition and may furnish the most important evidence in this field, especially in the absence of fossils. The significance of cross-lamination to the geologist, therefore, is clearly different from that of rock composition, which is primarily a feature of source or origin, and from that of grain texture, which is largely a result of the mode of transport.

A systematic study of cross-lamination is being undertaken with a three-fold approach: (1) development of a classification based on three-dimensional studies in which types are separated into natural groups that can readily be described and referred to by name; (2) a study of cross-lamination in representative modern environments including beaches, dune areas, and deltas to determine type, distribution, and abundance in each; and (3) application of the principles determined in (1) and (2) to selected rock formations of Paleozoic and Mesozoic age.

The classification proposed is based on features of structural development. These include (1) whether erosion and deposition or deposition alone are represented, (2) whether erosion surfaces are channels or planes, (3) whether these erosion surfaces are essentially horizontal or dip appreciably, and (4) whether the deposits are evenly bedded or thicker in a given direction. Nomenclature is based on physical characteristic of structures rather than on supposed or observed genesis.

METASOMATIC GRANITIZATION OF BATHOLITIC DIMENSIONS

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In the Nanga Parbat area (Northwest Himalayas), argillites with some thin limestone layers show early Tertiary synkinematic granitization. In the progressive series, phyllite—mica schist—biotite paragneiss—kyanite paragneiss—sillimanite paragneiss, granitization begins within the kyanite zone with microcline porphyroblast augen gneisses of granitic appearance containing relict kyanite in their groundmass. *Lit-par-lit* metasomatic feldspathization makes banded gneisses. Finally, coarse-grained granitic biotite gneiss forms, with subordinate relics of partly sillimanite-bearing paragneiss. The calcareous layers are not granitized and are, with structural continuity, preserved in the gneissic granite. Metamorphism and granitization progress both along and across the strike. The granitized body as mapped measures 25 by 60 miles. Postkinematic granitization forms replacement sills, dikes, and stocks.

In northwest Yunnan, red beds deposited after late-Triassic orogeny are statically transformed into plutonic masses of "granite porphyries". The horizontal bedding of the sediments remains completely undisturbed near the contacts and in relics preserved in the igneous-appearing rock;

there is not any structural feature indicating mechanical emplacement of magma. The groundmass of the "granite porphyries" has the clastic texture, grain size, and composition of the adjacent sediments. The apparent phenocrysts—plagioclase, quartz, and subordinate mafics—are porphyroblasts which metasomatically replace the sedimentary groundmass. Finally, the porphyroblasts become clear euhedral crystals with sharp boundaries. At least some of the quartz porphyroblasts have developed from small quartz pebbles. Apparent resorption surfaces are really surfaces of crystalloblastic growth. The granitized area mapped measures 13 by 20 miles.

POSSIBLY INTRUSIVE MASS OF SEDIMENTARY ROCKS, SANTA YNEZ RANGE, CALIFORNIA

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About 7 miles northeast of Santa Barbara, California, there is a body of Franciscan rocks (Jurassic?) in the Santa Ynez Range on the south side of the Santa Ynez fault. As exposed in plan, the Franciscan mass is 4 miles long and up to 1 mile wide and is surrounded by steeply dipping Cretaceous and Tertiary formations. Its contact with adjacent rocks is discordant and on the whole suggests an intrusive body. The Franciscan mass apparently protrudes into the younger formations. Moreover, in one place beds of competent Cretaceous(?) conglomerate are found as a blunt promontory jutting into the Franciscan terrain and terminating abruptly.

Of the Franciscan rocks involved, shale appears to be most plentiful, with graywacke next in abundance. Graywacke, chert, greenstone, and serpentine occur as chunks and lenses, large and small, enveloped in a matrix of sheared shale. This disorganized and unsystematic condition prevails throughout the Franciscan area.

The circumstances outlined above tend to indicate that the weak, incompetent Franciscan rocks were forced up, with something of a plastic behavior, into the strata which once overlay them. Ordinary faulting is an alternative hypothesis, but would not readily account for the irregular shape and internal structure of the mass.

TERRAIN AND PERMAFROST OF THE FAIRBANKS AREA, ALASKA*

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The Fairbanks area, located on the north side of the Tanana Valley adjacent to the Yukon-Tanana plateau, is divided into three geomorphic units: (1) the flood plain, (2) the hills, and (3) the depositional slope, between the hills and the flood plain. Each unit has distinctive lithology and permafrost conditions.

The flood plain is underlain by more than 400 feet of sands and gravels. The ground is permanently frozen to a depth of approximately 175 feet but has no large masses of clear ice. Nonfrozen areas are present. The flood plain is more suitable for engineering structures than is the depositional slope. The area is suitable for agriculture, but less solar heat is received here than on the south-facing slopes of the other two terrain units.

The depositional slope is composed mostly of muck with some sand and gravel. Muck is a black, fetid, sandy silt with high organic content. Permafrost extends to a depth of about 175 feet and thins toward the hills. Numerous large ice masses are present. This area is more favorable than the flood plain for agriculture because more solar heat is received. Clearing of the land, however, causes melting of the ice masses, and consequent pitting of the fields makes them unusable. Structures built in this area are subject to destructive settling.

The hills are of schist blanketed with 1 foot to 80 feet of silt. Permafrost is generally absent, especially on the south-facing sides. The lower gentle slopes are favorable for agriculture as the solar heat received is high.

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KODACHROME MOVIES OF 1940 AND 1942 ERUPTIONS OF MAUNA LOA

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These are typical scenes of the eruption of Mauna Loa of 1940, which was confined to the summit crater. General views and details of action are shown of the flank fissure eruption of Mauna Loa in April 1942. This movie is a silent Kodachrome moving picture, with descriptive remarks from the floor by the exhibitor.

RIM ROCKS OF SYCAMORE CANYON, ARIZONA

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The rim rocks of Sycamore Canyon, on the southwestern margin of the Colorado plateau, include the Kaibab formation of Middle Permian age, the Moenkopi formation of Lower Triassic age, and gravels and basalts of Cenozoic age. These have been broken into blocks by normal faulting.

The alpha, or upper, member of the Kaibab formation, typified by fossiliferous magnesian limestones, and the beta member, represented by sandy limestones containing much bedded chert, are both present. Correlation with sections in the surrounding region shows that this formation has increasing thickness, fewer dolomites, greater amounts of bedded chert, and a decrease in sandiness from east to west.

In the Sycamore Canyon area are found the southwesternmost exposures of the Moenkopi. A thick basal conglomerate is present. Above this are two, possibly three, divisions comparable to those recognized by Welles in the Little Colorado Valley.

Cenozoic gravels are of two types, one derived from formations similar to those exposed today in the Bradshaw Mountains and Black Hills to the southwest, and the other from local outcrops of the Shinarump conglomerate. Those of the first type are angular, and evidence suggests that they were laid down in Miocene-Pliocene time as fluvial deposits from a source in near-by mountains. The second gravel type is believed to have been derived from residual weathering of the Shinarump conglomerate in Pleistocene-Recent times.

Basalts, probably of Pliocene age, occur along both rims as flows and dikes.

Faulting has been both pre- and post-basalt. The dominant direction of strike is northwesterly. Graben structures are common.

NEW UPPER CENOZOIC EXPOSURES IN NORTHEASTERN ALAMEDA COUNTY, CALIFORNIA

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Excavation for the Delta-Mendota Canal in the outer foothills of the Diablo Range west of Tracy affords an oblique section of tilted upper Cenozoic continental beds approximately 460 feet thick and of Orindan aspect. These rest with erosional and locally angular unconformity on fresh-water fine clastics 0 to perhaps 50 feet thick which appear conformable on characteristic Neroly sandstones. Loose stream deposits above the upper Cenozoic beds have yielded Pleistocene vertebrate fragments. Continuity of the exposures and the unconformity noted will be lost as the canal is lined.

DISTRIBUTION OF LIVING OSTRACODS, NEWPORT BAY, CALIFORNIA

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An ostracod distribution chart shows the number of live specimens counted in the following salt-water environments: (1) tidal flat; (2) marsh channel; (3) lagoon channel; (4) bay-mouth and subtidal channel; (5) open-sea rocky-tide pool.

The species characteristic of the above environments are defined as ostracod "biofacies". The plants, as well as the ostracods, differ with exposure to tide, waves, type of bottom, pH, salinity, and temperature. The plants appear to be a major biologic factor influencing the distribution of Newport Bay ostracods.

Live ostracods from a few of the most contrasting environments of Newport Bay are shown in 16mm. movies, as well as pictures of each collecting station.

PALEOECOLOGICAL INTERPRETATIONS FROM OSTRACODS

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Ecological distribution of Recent salt-water ostracods is shown from studies of submarine bottom samples across the San Pedro Channel and from collections along the California coast.

These Recent occurrences are classified into ostracod biofacies which are typified by the following species from shallow to deep: (1) *Anomocytheridea beaconensis;* (2) *Loxoconcha* cf. *elliptica;* (3) *Clithrocytheridea pedrosensis* and *Cythereis* aff. *rugipunctata;* (4) *Loxoconcha lenticulata;* (5) *Cythereis pacifica* and *C. glauca;* (6) *Hemicythere californica;* (7) *Cythereis simiensis* and *C.* cf. *ericea.*

The defined biofacies are applied to fossil Pliocene occurrences in the Etchegoin formation of the Midway-Sunset Oil Field. The geologic range of ostracod environment indicators is shown from studies of Pliocene outcrops in Humboldt, Ventura, and Orange counties, California. The depth of deposition of these sediments is suggested.

BLANCAN HORSE FROM NEAR WALNUT CREEK, CALIFORNIA

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Remains of fossil vertebrates have been obtained from several new localities in the terrestrial beds of the San Francisco Bay area since 1941. Most of these discoveries were achieved through continued search of excavations made for new roads and housing developments. The unearthing of a palate of *Equus* sp. at Livorna Heights, just south of Walnut Creek, is considered to be of particular stratigraphic significance. The fossil was collected from sediments which have been previously mapped as Orinda formation. This palate bears an incomplete milk dentition. Comparison of this specimen with milk dentitions of late Tertiary and Pleistocene equids leads to the decision that the Livorna Heights horse belongs in the *Equus* (*Hippotigris*) = "*Plesippus*" group. The hippotigrine group typifies the Blancan of North America. This horse, therefore, reveals a still younger age than has been previously suspected for certain of the beds of the "Orinda" complex.

CONSTITUTION OF VALLEY GLACIERS

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Recent glaciological investigations show that the individual ice streams composing a trunk valley glacier may have the following arrangements: (1) juxtaposed—the ice streams lie side by side, and each extends to the floor of the glacier; (2) inset—an ice stream is inlaid within the glacier so that its bottom does not reach the valley floor; (3) superimposed—an ice stream rests upon the surface of the glacier. Complex valley glaciers may be composed of ice streams in all three positions.

Concepts of glacier flow evolved by Demorest provide a plausible mechanism by which these positions are developed, and degree of discordance in valley floors largely determines the arrangement ultimately attained. If valley floors are accordant, a juxtaposed position eventually results because the waxing force of gravity and obstructed gravity flow in a tributary glacier is pitted against the waning force of obstructed extrusion flow from the trunk glacier. The tributary forces its way

into the main valley and takes up a juxtaposed position with the trunk glacier. If discordance in valley floors is less than the thickness of the trunk glacier, an inset position develops owing to the superiority of gravity over obstructed extrusion flow. If the discordance is greater than the thickness of the trunk glacier a superimposed position results. Temporary or local superimposed or inset relations may be developed by exceptionally rapid advances, but any superimposed ice stream shortly becomes inset by sinking into the underlying ice, at least in temperate regions.

DIVING OPERATIONS IN SUBMARINE CANYONS

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Unusual California weather in January brought a long-awaited clearing of the water in the submarine canyon heads off La Jolla. Photographs taken by Frank Haymaker on the steeply sloping floor of Scripps Canyon (*see* exhibits) show the vertical rise of stratified rock above a floor deposit of muddy sand with great masses of kelp. In places the photographs show overhanging rocks jutting out from the walls. The vertical ridge between a tributary entering the main canyon at grade is shown, and a hanging valley can be seen. Along the side of the canyon fill there is a small gutterlike depression, presumably due to slumping. In La Jolla Canyon, a ridge of an alluvial cobble formation is shown with precipitous walls rising above the floor of a gully. Elsewhere a large boulder of clay was found at the foot of a tributary valley where its gradient flattened near the juncture of the main valley.

The photographs and description by the diver of the canyons show such complete agreement with the land canyons in the near-by cliffs that the conclusion is almost inescapable that the submarine canyons were formed by the same cause. As yet no one has explained these land valleys as the product of anything but subaerial erosion.

ORIGIN OF OREGON PRICEITE

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Despite the fact that priceite was first described as a new mineral from Lone Ranch, Curry County, Oregon, and that the mineral was commercially mined in 1892, very little is known concerning its occurrence or origin. The tunnels, now caved, are all in serpentine, which makes this occurrence for priceite unique. A colloform white mineral found on the surface and often mistaken for priceite is calcite, which frequently contains a minute core of priceite.

The origin of the priceite is probably related to the intrusion of a prominent rhyolite dike which parallels the priceite zone. This dike is unusual in that it contains graphite disseminated throughout most of its length. Reaction of this intrusive and its boron emanations with a concealed calcareous rock probably accounted for both the graphite and the priceite.

Spectrographic studies show the presence of boron in the rhyolite, and several elements such as strontium and copper occur in unusual concentrations in both the rhyolite and priceite, confirming to some extent their genetic relationship.

GROUND SLOTH THINOBADISTES FROM THE PLIOCENE OF FLORIDA

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In 1919 and 1921 O. P. Hay established the genus *Thinobadistes* on the basis of an astragalus and associated foot material, collected many years previously near Williston, Florida, by J. B. Hatcher. To this genus can now be assigned much fossil ground-sloth material obtained by field parties of Childs Frick at apparently the same locality, now known as the Mixson Bone Bed. The characters recognized on the basis of the additional remains indicate the presence of a mylodont sloth more primitive than the Pleistocene *Paramylodon*.

PEDIMENT CONCEPT APPLIED TO CERTAIN CONTINENTAL FORMATIONS OF THE COLORADO PLATEAU

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Thin but widespread conglomerates such as the Shinarump of Late (?) Triassic age, the Buckhorn of Early (?) Cretaceous age, and the Dakota of Cretaceous age are interpreted as resulting mainly through pedimentation. Recent pediments are confined to arid and semiarid regions, but climatic environment alone is not the essential factor of formation. Pediments appear to result whenever and wherever fluvial action takes place and where there is ample loose rock detritus to satisfy quickly the transporting capacity of the temporary or permanent streams that are present. When the supply of detritus is nicely balanced for long periods against the energy of the streams, pediments expand and become increasingly stable. Although most recent pediments are forming in regions that have undergone extensive degradation probably in the past they formed mainly after long-continued aggradation since either process ultimately results in the balance necessary for pediment formation.

Extensive areas of the Colorado Plateau have at several times in the past reached grade through the deposition of widespread marine and nonmarine beds. Under stabilized conditions after the attainment of grade, thin gravel sheets were formed. The building up and expansion of these coarse deposits apparently required long periods of time. The Shinarump conglomerate involves the lapse of the entire Middle Triassic; the Buckhorn conglomerate represents most of the Early Cretaceous, and the Dakota a good portion of the Late Cretaceous. In such cases the time loss is not strictly accounted for by the unconformity at the base of the conglomerates—it is represented by the conglomerates themselves.

STRATIGRAPHIC EVALUATION OF SOME UPPER PALEOZOIC INDEX FOSSILS OF ARIZONA

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Stratigraphically important Late Paleozoic invertebrate fossils of Arizona are described, and their correlative value in relation to the out-of-State standard sections is discussed. 1—Upper Devonian strata of southeastern Arizona older than the Martin limestone, a correlate of the Hackberry shale of Iowa by original definition (*Spirifer hungerfordi* fauna), include: equivalents of the Independence shale of the Iowa Devonian sequence (with *Macgeea parva, Petrocrania famelica, Schizophoria amanaensis, Pugnoides schucherti, Hypothyridina emmonsi, Spirifer strigosus*, etc. Mescal Mts.), and of the Cedar Valley limestone (with *Spirifer iowensis, Sp. cedarensis, Sp. eurudeines*, etc. Superior-Lake Roosevelt). Above the same datum are: the Lower Ouray limestone (*Paurorhyncha endlichi* in strata immediately succeeding the topmost *Hexagonaria* reef on the Pinal Creek, Globe-Tucson), and possibly an equivalent of the Percha shale (*Paurorhyncha cooperi*. Swisshelm Mts.). 2—Stratigraphic interrelation between the analyzed autochthonous Lower Mississippian assemblages (*Spirifer centronatus* fauna) and the eastern migrants (corals, blastoids, and brachiopods) affords a satisfactory medium for an advanced comparative zonal differentiation of the Escabrosa and Redwall limestones. 3—Description of a number of Pennsylvanian and Permian species discussed in the writer's previous publications on the stratigraphy of Arizona but not illustrated: new species; those of intercontinental affiliations (South America, China); and those permitting a closer correlation with the corresponding strata of New Mexico and Texas, but hitherto unreported from Arizona.

ARDUINITE FROM TINTIC, UTAH

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The rare zeolite, arduinite, has been found in the Tintic district, Utah. This is the first American and second world occurrence of the mineral to be noted so far. It is associated with quartz in

rhyolite porphyry. The mineral is red and exhibits a radiating structure with radii varying between 2 and 20 mm in length. The optic properties correspond to the type arduinite from Italy, but comparison of the chemical analyses shows that the Tintic mineral contains more CaO and less Na_2O than the type material.

DEFLATION PHENOMENA IN THE LIBYAN DESERT OF EGYPT

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Many parts of the Libyan Desert are strewn with stones of varying size and degree of proximity. Such a part lies near the north rim of the Faiyum depression, where the annual rainfall is about 3mm. Here, the bedrock, a 2-degree dip-slope plain of unconsolidated quartz sand of Oligocene age and fluvial origin is covered with a very thin veneer of aeolian sand dotted with chert and quartz pebbles. These latter range in size from a few millimeters to several centimeters; most are ventifacts, and all the cherts are patinated and dark brown. Occasionally one encounters "thermally" split chert pebbles with the resulting fragments still in contact or separated at most a short distance. The fracture surface varies from gray in fresh splits to dark brown in old splits. One such chert specimen, consisting of halves separated by 3 centimeters, was of uniform dark brown color. Several Egyptian archaeologists to whom it was shown concurred independently that the degree of patination indicated an age at least older than the first dynasty (4000 B.C.). If so, then we may conclude that this stone split 6000 years ago and has remained laterally undisturbed since. It follows that sheet wash plays little or no part in erosion at this locality today. Wind removes the small elements of the surface, while elements large enough to resist its transportive power are let down more or less vertically by the net plucking away of support.

STRUCTURE OF A PORTION OF THE SAN ANDREAS RIFT IN SOUTHERN CALIFORNIA

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An area approximately 20 miles long and 5 miles wide along the San Andreas rift in southern California between Palmdale and Elizabeth Lake was mapped. The area includes a portion of the Mohave Desert and two ridge zones separated by a trough along the rift.

The ridge zones are principally old crystalline rocks; the trough is underlain by a long, narrow strip of sediments which outcrop in a low "center-trough" ridge. These sediments are part of the Anaverde formation of Pliocene age. The older rocks of the ridge zone are in bands striking east or slightly north of east. This trend is cut by the rift which, in this area, has a strike of approximately N. 65° W.

Offset of terrace deposits suggests horizontal displacements along the rift of 5–6 miles since the Pleistocene, the northeast side having moved relatively southeastward. There is no definite evidence that strike-slip displacement began earlier than the Pleistocene although suggestions of greater age of the rift were found.

Distribution of structures suggesting displacement in a direction opposite to that displayed in recent faulting is believed to have resulted principally from differential vertical uplift.

GEOLOGY OF THE EAST-CENTRAL PORTION OF THE HUACHUCA MOUNTAINS, ARIZONA

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The area discussed embraces rock units ranging from pre-Cambrian to Tertiary in age. The basement pre-Cambrian granite is overlain by cliff-forming Middle Cambrian Bolsa quartzite. The Bolsa is succeeded by sandstones, shales, and limestones of the Cochise formation. The Upper Cambrian Abrigo formation is distinguished from the Cochise by a distinctive trilobite fauna. The Rincon limestone marks the top of the Cambrian section. The Devonian system is represented by

two Upper Devonian units, the Picacho de Calera and Martin formations. The Lower Mississippian Escabrosa limestone is a prominent cliff former. A thrust sheet outlier of the Permian Snyder Hill formation rests upon pre-Cambrian granite. Cretaceous conglomerate, overlain by maroon siltstones with interbedded sandstones and limestones, rests upon Permian strata. Granodiorite, rhyolite, and andesite porphyries intrude Cretaceous beds.

Extensive thrust faulting dominates the structural pattern; the crest of the range is defined by Mississippian limestone overthrust upon tilted Cretaceous strata. Subsidiary folding, and block faulting of subsequent developement, are companion features.

Mineralization in the area includes scheelite in quartz veins conformable with the basal Cochise member. Gold-bearing pyritic quartz veins are found in, and adjacent to, the granodiorite. Mining prospects showing manganese oxides associated with solution channels in the Abrigo limestone were noted.

CRYPTOZOIC-CAMBRIAN CORRELATIONS IN CALIFORNIA, NEVADA, AND UTAH

HARRY E. WHEELER

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Lithostratigraphic and time-stratigraphic correlations of the latest Cryptozoic (pre-Cambrian) and Cambrian marine sediments have been made from the Marble, Providence, and Nopah ranges in southeastern California, through the Johnnie, Groom, Delamar, and Pioche districts of southern Nevada, to the Wah Wah, House, and Deep Creek ranges in western Utah.

Throughout this linear distance of 475 miles the pre-Cambrian and Lower Cambrian Prospect Mountain quartzite is overlain by the Bright Angel group or its lithogenetic equivalent which, in turn, is superseded by the Middle Cambrian limestones and dolomites. In this sequence 10 rock units are recognized as extending throughout the region between the Groom district, Nevada, and the Wah Wah Range, Utah. This regional stratigraphic integration calls for the designation of three new formations and one new member. In the interest of unification and simplification of regional rock-stratigraphic nomenclature, names of several previously defined units are rejected as synonyms.

On the basis of reports on 46 faunal occurrences, time-stratigraphic units (zones) are delineated throughout the Lower and Middle Cambrian Series, and in the lower part of the Upper Cambrian. In some cases apparent parallelism exists between rock and time-rock units; in others notable temporal transgression is evident.

WHITE EAGLE TALC DEPOSIT: AN EXAMPLE OF STEATITIZATION OF GRANITE*

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A deposit of commercial talc, formed chiefly by alteration of biotite granite, occurs at the White Eagle mine in the Inyo Range of California. Quartzite and dolomitic limestone of Paleozoic age border portions of the deposit and, near the contact, have themselves been altered to talc. The main body, which is triangular in plan, is bordered principally by granite and contains many granitic residua.

From unaltered granite there is a transition into relatively pure talc. In some exposures this transition is gradational through a distance of several feet; in others the alteration is complete within a few inches. Incipient stages of the alteration are indicated by the decomposition of biotite and hornblende and the formation of limonitic veinlets; in the more intense stages all major minerals (quartz, microcline, orthoclase, and plagioclase) are replaced by talc.

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PACIFIC COAST BRANCH OF THE PALEONTOLOGICAL SOCIETY

AGE OF POST MINT CANYON MARINE BEDS

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Recent investigations into the paleontology and stratigraphy of the Modelo (?) formation of Kew in the eastern end of the Ventura Basin clearly demonstrate that it unconformably overlies the Mint Canyon formation with a marked angular discordance. Further, the molluscan fossils found indicate that the Modelo is approximately equivalent in age to parts of the Cierbo and Neroly of middle California. Among the more important fossils found in the Modelo(?) are: *Astrodapsis* cf. *tumidus*, *A.* aff. *fernandoensis*, *Aequipecten discus*, *Anadara trilineata* (Elsmere Canyon variety), *Anadara* n.sp. aff. *A. obispoana*, *Clementia* sp., *Lyropecten crassicardo*, *L. estrellanus* ss., *Ostrea titan* s.l., *Cancellaria tritonidea*, *Trophosycon ocoyana*, and *Turritella cooperi*. Locally foraminiferal assemblages indicative of an upper Mohnian age have been identified. Except for *Astrodapsis fernandoensis* ss., *Dendraster* sp. (*excentricus auct.*), and *Patinopecten lohri* all the important species of the Elsmere Canyon fauna have been found in strata at the base of the Modelo(?). Whether or not this is indicative of an upper Miocene age for the Elsmere Canyon fauna is uncertain. *Hipparion* has been found in the Mint Canyon strata a few feet below the unconformity.

RELATIONSHIP OF CALIFORNIA UPPER MIOCENE-LOWER PLIOCENE VERTEBRATE AND INVERTEBRATE FAUNAS

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The Mint Canyon vertebrate fauna can be dated as pre-upper Mohnian of the foraminifera sequence and as at least pre-Neroly in the molluscan scale. The *Hipparion* tooth from the Puente formation described by Stock appears to come from the *Bolivina uwigerinaformis* foraminiferal zone, and thus to be of approximately the same age as the Mint Canyon *Hipparion* teeth. Both occurrences are probably equivalent in age to the Briones "stage" of the molluscan workers.

In the San Francisco Bay-Mount Diablo region the most abundant occurrences of *Hipparion* are in the Green Valley and Siesta, though other less complete materials occur in the Orinda and "Neroly" formations. *Nannippus* has been found in the Orinda and Neroly formations, and a primitive *Pliohippus* occurs in the Orinda. No other Equidae have been collected from the Orinda, Neroly, or from the older formations of this area. The type Orinda formation has been shown to be, in part at least, as old as the Neroly, and it is possible that it may be in part still older.

In summary, it appears on the basis of the evidence now available that the Clarendonian age of the vertebrate paleontologists includes in its lower part the Mohnian and Delmontian stages of the foraminiferal sequence and the Briones, Cierbo, and Neroly of the molluscan sequence.

It also seems that, in terms of the vertebrate scale, very little time is represented by the Briones, Cierbo, and Neroly molluscan sequence and by the Mohnian-Delmontian foraminiferal sequence.

RELATION OF MARINE CYCLES TO THE FAUNAL EVIDENCE

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A slight downwarping of ocean basins and upwarping of continents when there is compression leading toward mountain building somewhere on the earth may be the chief cause of marine with-

drawals, but when the pressures are relieved the warping may relax and the waters again flood in over the land. If so, marine cycles of deposition, consisting of transgressions (overlaps) and regressions (offlaps), may be essentially world-wide in their effects, except where particularly strong local movements of the land may locally vary the pattern. Thus we may account for the large measure of success so far attained in applying the geologic time scale. The natural points of divisions between eras, periods, and epochs are the times of maximum withdrawal of the sea, which also means the horizons of most widespread unconformities. If fossil correlations, although hampered by the time durations of migrations and by barriers which have kept different regions from having the same species, can indicate on the whole which transgression in one region corresponds to which in the other region, and which regression to which, then the boundaries should fall at the corresponding points of maximum withdrawal between. Thus the logical position for the Miocene-Pliocene boundary in California is the point of maximum withdrawal between the Delmontian upper Modelo-Neroly regression and the Jacalitos-Elsmere-Repetto transgression. If so, the time of widespread andesitic lavas in central and southeastern California and the Ricardo upper member of the Mint Canyon formation would belong to the uppermost Miocene.

TEMPORAL POSITION OF OSTEOBORUS

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Osteoborus littoralis (VanderHoof) has been placed in the upper Miocene Santa Margarita formation by Barbat and Weymouth on the basis of an associated invertebrate fauna. Recent studies indicate that *O. littoralis* structurally stands between a specialized undescribed species of *Tomarctus* from the Ricardo fauna (Lower Pliocene) and *O. diabloensis* Richey from the Black Hawk Ranch fauna (Lower Pliocene).

If the locality of *O. littoralis* was unknown the species would be placed in the Clarendonian on the basis of its phyletic position. *Osteoborus* would then have a Clarendonian-Hemphillian range. Such a temporal position for the genus would make it useful as an index to Miocene-Pliocene boundaries comparable in position to *Hipparion*.

MIOCENE-PLIOCENE BOUNDARY IN CALIFORNIA AS A TYPICAL EXAMPLE OF SERIES—EPOCH BOUNDARY PROBLEMS IN CORRELATION

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California's Miocene-Pliocene "boundary" problem is typical of Series-Epoch "boundary" correlations in general. Factors involved include: (1) typology; (2) general principles of paleontologic correlation; (3) particulars of specifically pertinent correlations.

(1) Typology necessarily involves priority in definition, yet such "original meaning" seems seldom viewed in its true historical context, so that interpretations degenerate into legalisms. Lyell's subdivision of the Cenozoic, for instance, involved a geologic chronology of no nicer refinement than units of Series-Epoch magnitude provide; thus modern definitions of his Series-Epochs (Miocene, etc.) in unit terms of Stage-Age magnitude (Burdigalian, Plaisancian, etc.) seem not truly typological. Accuracy and clarity would seem enhanced were Series-Epoch "boundary" problems: (a) discussed in terms of commensurate refinement ("Mio-Pliocene", "Oligo-Miocene", etc.), or (b) divested of Series-Epoch terminology and discussed within that Stage-Age (or even Zonal) category of refinement required by "boundary" correlations when refined far beyond the factor of error involved in merely correlating Series as units.

(2) Application of the basic correlation principles (Steno's, Smith's, Quenstedt's, Oppel's, Uniformitarianism, plus sundry corollaries) often loses sight of their essentially pre-Darwinian origin.

This is, of course, not to imply that paleontologic correlation should therefore be un-Darwinian; yet it is to imply that pure paleobiology is perhaps often overemphasized at the expense of basic biostratigraphy in many modern correlations. Moreover, at Stage-Age level of refinement in cor-

relation (especially in "boundary" problems) facies factors become increasingly important; yet, in current stratigraphic geology, there is little uniformity in definition of the term facies ("aspect" —aspect of what?); nor is it customary to distinguish between *facies* (a) in petrology (diversity in aspect of lithogenetic unity), (b) in biology (diversity in aspect of faunal unity, fossil or living), (c) in stratigraphic geology (*diversity in aspect* of a *chronologic unit*).

(3) Prerequisite to ascertaining the *particular* European-Californian *correlations* under discussion —Stage-Age level refinements in this instance and therefore several in number through the more general Mio-Pliocene interval—are well disciplined provincial chronologies founded upon controlled biostratigraphic sequences. Currently in California sequences of mammal, megafossil, and foraminifer faunas are principally involved.

ECOLOGY OF THE MIOCENE-PLIOCENE BOUNDARY IN THE LOS ANGELES BASIN

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The southeast side of the Los Angeles Basin contains a rather complete Tertiary section and presents an ecologic history which, in general, is typical for most of the basin. Using the known depth ranges of Recent species of Foraminifera as a guide, the Miocene-Pliocene boundary over much of the Los Angeles Basin was deposited at oceanic depths ranging from 4000 to 6000 feet. There is no outstanding faunal break at the top of the Miocene; neither is there in most areas a pronounced lithologic break, especially where no unconformity exists at the contact.

A chart is presented showing the probable ocean depths of accumulation for the Vaqueros to Recent sediments present in the Newport—San Joaquin Hills area.

CORRELATION OF THE LATER CENOZOIC HOLARCTIC CONTINENTAL MAMMALIAN FAUNAS

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These considerations are based, first, on "typology", and second, identity of genera and the stage of evolution of the species in those genera in their Holarctic area of dispersal. In "typology" effort has been made to correlate the original marine and brackish type areas and their time-rock units as interpreted by Lyell and other original authors with continental beds and their mammalian faunas. The inception of glaciation as evidence for the beginning of Pleistocene time is disregarded in favor of "typology".

The genera of most significance in this correlation are:
Equidae—*Anchitherium, Merychippus-Hipparion, Pliohippus-Equus*
Castoridae—*Eucastor-Dipoides, Chalicomys-Castor, Amblycastor*
Machairodontidae—*Sansanosmilus-Machairodus*
Canidae—*Hemicyon, Amphicyon*
Mustelidae—*Eomellivora, Plesiogulo*
Ursidae—*Indarctos, Agriotherium*
Gomphotheriidae—*Gomphotherium, Serridentinus.*

See chart, next page.

CORRELATION CHART

	North America	China and Mongolia	India and Burma	Europe
	Rancho La Brea *Irvington*	*Choukoutien*	*Boulder Conglomerate*	*Eringsdorf* *Tegelen*
PLIOCENE*	BLANCAN	Nihowan	Pinjor	VILLAFRANCHIAN
	////////////////////		Tatrot	ASTIAN
	HEMPHILLIAN	Ertemte	Dhok Pathan	PONTIAN
		(Hipparion faunas)	Nagri	
	CLARENDONIAN		Chingi	SARMATIAN
	///?////////////////////	////////////////////	////////////////////	/////?////////////////////
MIOCENE*	BARSTOVIAN	Tun Gur-Shanwang	Kamlial	VINDOBONIAN
		////////////////////		
	HEMINGFORDIAN	Loh	Fatehjang	BURDIGALIAN
	ARIKAREEAN			
		////////////////////	////////////////////	AQUITANIAN

*Ages indicated in Lyell's type sections.

AGE OF THE MODELO (?) BEDS IN HASKELL AND DRY CANYONS, NORTHERN LOS ANGELES COUNTY, CALIFORNIA

ROBERT C. WHITE AND EDWIN C. BUFFINGTON

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A part of the marine Modelo (?) beds of the Ventura Basin is exposed in Dry Canyon and Haskell Canyon, about 5 miles north of Saugus. Here approximately 670 feet of Modelo (?) sandstones siltstones, and shales lies unconformably upon the terrestrial Mint Canyon formation.

One of the largest invertebrate faunas thus far known from the Modelo (?) beds has been collected. On the basis of presence of *Astrodapsis* cf. *tumidus*, *Astrodapsis* cf. *whitneyi*, *Pecten* (*Lyropecten*) *crassicardo*, *Pecten* (*Aequipecten*) *discus*, *Turritella carrisaensis*, and *Ostrea titan* s.s. correlation is made with the Neroly stage of the San Pablo group of central California, and an upper Miocene age is assigned to the assemblage. Four new species occur in the collection.

Astrodapsis aff. *fernandoensis* and *Trophosycon ocoyana* from the uppermost Modelo (?) beds have affinities with forms in the Elsmere Canyon fauna, considered typical of the so-called lower Pliocene.

MIOCENE-PLIOCENE BOUNDARY IN THE LOS ANGELES BASIN FROM THE VIEWPOINT OF THE MICROSTRATIGRAPHER

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Wells drilled in the central portion of the Los Angeles Basin normally penetrate an unbroken depositional sequence from the Upper Pliocene into the Mohnian stage of the Upper Miocene. For some 20 years oil company microstratigraphers have placed the Miocene-Pliocene boundary at the base of the continuous occurrence of such typical Repetto foraminifers as *Karreriella milleri* Natland, *Hopkinsina hispida* (Schwager), *Bulimina rostrata* Brady, etc. and at the approximate upward limit of *Rotalia garveyensis* Natland, *Uvigerina hootsi* Rankin, and a related costate *Uvigerina*. Many foraminiferal species are common to both the Lower Pliocene Repetto and the Upper Miocene Delmontian, and in the Delmontian there are rare intermittent occurrences of some of the more typical Lower Pliocene forms. While there is no marked lithologic break at the Repetto-Delmontian contact, there is a rather pronounced change in the preservation of the foraminiferal faunules since the tests of the majority of the Miocene forms are generally so badly crushed that only a small portion of the fauna can be extracted from the samples by washing. The Miocene shales are generally more laminated, and short intervals of the hard platy "poker chip" type shale frequently are encountered a short distance below the contact; platy shales become more abundant with depth, and the color gradually changes from the dominant hair brown of the lower Repetto to the dark chaetura drab of the upper Miocene. The Foraminifera are rather evenly distributed in the more massive Pliocene shales, while in the more laminated Miocene ones they normally are concentrated in thin layers.

AGE OF THE BASAL MODELO (?) FORMATION IN REYNIER CANYON

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An upper Miocene marine molluscan fauna occurs in basal Modelo (?) sandstones that flank Reynier Canyon of the southeastern portion of the Ventura basin, Los Angeles County, California. Here two outliers of these beds are nonconformable on continental siltstones and tuffs of the Mint Canyon formation. The Modelo (?) sandstones grade upward into punky diatomaceous shales also of the Modelo (?) sequence, that contain *Anadara* cf. *obispoana* and a foraminiferal fauna reported to be Mohnian in age. The shales of one outlier are unconformably overlain by other marine sediments.

The upper Miocene age of the basal Modelo (?) beds is indicated by the presence of *Clementia* cf. *martini*, *Dosinia arnoldi*, *Lyropecten estrellanus* ss., *Spisula albaria*, *Tivela diabloensis*, and a large *Ostrea*. Approximately half of the forms in the Reynier Canyon Modelo (?) fauna also occur in the Elsmere Canyon fauna; these include *Laevicardium centifilosum*, *L. quadragenarium* var. *fernandoense*, *Lucina nuttallii*, *Cancellaria elsmerensis*, *C. hemphilli*, *C. tritonidea*, *Surculites remondii*, *Murithais eldridgei*, *Nuculana taphria*, and *Turritella cooperi*. The Elsmere Canyon species *Patinopecten lohri*, *Astrodapsis fernandoensis*, and *Dendraster* sp. are missing from the Modelo (?) fauna.

THE SEISMOLOGICAL SOCIETY OF AMERICA

ENERGY OF EARTHQUAKES

MUSTAFA AYDINOGLU

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A study of the energy in earthquakes as deduced from detailed measurements of seismograms has been undertaken. Distribution of energy in groups and comparison of energies so computed with that obtained from the magnitudes will be presented.

EARTHQUAKES AND ROCK CREEP

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An investigation based on magnitudes of a number of earthquakes and aftershocks as determined by Gutenberg and Richter indicates that the occurrence of aftershocks can be explained in terms of elastic afterworking or creep in rocks. In the case of the Long Beach aftershocks the creep had a dual form. For the first 0.14 day it was purely compressional in nature. Thereafter it was purely shear.

The study has been extended to include a numbe. of earthquake sequences including the Hindu Kush and Tonga deep-focus groups. Each sequence forms an elastic, plastic, or combination elastic-plastic creep series. The evidence suggests that the rock masses, in which these sequences have their origin, behave as single mechanical units even though, as in the case of the South American Deep Focus Sequence, they extend over 30 degrees of latitude. The evidence suggests that these large masses accumulate elastic strain for time intervals up to 30 years or more.

California earthquakes, having epicenters west of the Sierras, form an elastic creep series, herein termed the San Andreas sequence, which begins approximately August 22, 1914, and continues to date.

The results of this investigation show that Richter's magnitude scale and its extension by him and Gutenberg is much more precise than was originally anticipated.

AMPLITUDES OF P WAVES

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Extending the method of Nakano, the effect of azimuth of the path and the angle of emergence on the amplitude of P waves is investigated for faults of several different dips and motions of several types along these faults.

SEISMOGRAPH STATION NEAR HUNGRY HORSE DAM, MONTANA

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In November 1947 a fully equipped Benioff small-model seismograph was placed in operation near the site of the Hungry Horse Dam which will soon be under construction on the South Fork of the Flathead River in northwestern Montana. The new station replaces the station formerly at Overton, Nevada. It is being operated by the U. S. Bureau of Reclamation with technical assistance from the Coast and Geodetic Survey. The station was established because the area has been seismically active in recent years. The Bureau of Reclamation wishes to locate the active faults and also to determine stresses accompanying future earthquakes which may influence the design of the new dam.

DIFFICULTIES IN THE ACCEPTED THEORIES OF SEISMIC WAVE PROPAGATION

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This theory suffers from being so oversimplified that its conclusions are not readily comparable with observations. This defect we hope will be surmounted by the new electronic computing machines. But there are other more serious defects in the basic formulation of the theory. The interface conditions of Knott are not sufficient to determine the solution. If we have a point source we may determine secondary waves following Jeffreys (Cambridge Philos. Soc., Pr., Vol. 23, p. 472–478, 1926), and it is possible but not probable that this solution is correct. But another solution is also consistent with all the stated conditions—namely, the solution where the only secondary wave is the negative of the incident wave. It will be objected that such a solution is obviously to be rejected. This is correct, but if we consider Knott's solution for grazing incidence at a free surface we find that this obviously wrong solution is just the one we are led to by the accepted procedure. If we doubt the validity of this result we must also doubt the validity of neighboring solutions. Energy and momentum considerations show that only the plane case of normal incidence can be strictly correct. In almost all other cases the Knott solution does not give conservation of momentum.

The case of the quarter-infinite medium, bounded by the x, y-plane (free surface) and the y, z-plane (source), has been studied to show that the error arose by using secondary solutions which are individually not possible solutions of the problem.

USE OF LARGE COMPUTING MACHINES IN SEISMOLOGY

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The use of large-scale electronic digital computers such as the Eniac, Univac, Edvac, and others to be developed may be expected to create very important developments in seismology as soon as such machines become available. Using these machines, it is possible to approach the solution of many problems that heretofore have been too complicated to merit serious consideration. A speed-up of the rate of calculation production by a factor of 50,000 is about what is to be expected in the very near future.

For example the solution of pulse-propagation problems can be followed in great detail. The process of the release of energy by a slip along a fault can be studied in detail for many fault shapes and many orientations and for many initial stress distributions. The generation of secondary types of waves at discontinuities can be studied in great detail.

The method of attack is to replace the partial differential equations by approximating partial difference equations and to solve these latter by direct integration. By such a process we remain close at all times to the fundamental physical relations and so avoid extraneous (nonphysical) solutions.

The trend indicated appears to be an extremely healthy one for seismology as it makes mathematical physics much more useful than formerly. Formerly mathematical physics had a tendency to discuss problems, many of which were too much simplified to be applicable to the problems of seismology. The new machines promise to allow us to approach closer to our real problems.

TREND OF ENGINEERING DESIGN SINCE THE LONG BEACH SHOCK OF MARCH 10, 1933

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The Field Bill, requiring schools to be designed to resist earthquakes, was a result of the Long Beach shock. Administration of the law has been good in general. Design of schools has been good; many hazardous existing structures have been repaired. Much work on existing schools

remains to be done. Unfortunately, there is opposition to the law. In its enforcement, architects, engineers, contractors, and school boards are needlessly antagonized over petty but costly details. Without authorization of law, the enforcing agency arrogated to itself checking for fire safety. Unless intelligence is used by all interested parties, there is no certainty that the law can be maintained. Establishment of an Earthquake Research Institute would go a long way toward settling a number of problems.

The small one- and two-story commercial buildings have always been responsible for much of the property damage and loss of life in past shocks. Adoption of the Reilly Act after 1933, and earthquake provisions in many building codes, has resulted in a great improvement in the design of this type of structure.

The war period gave a great impetus to the use of hollow concrete blocks. Such structures are inherently hazardous in earthquakes unless properly designed and reinforced. Much of this construction has been inadequately controlled, or not controlled at all. The situation in regard to this type is serious.

Much technical investigation remains to be done. Selected vibration studies of actual structures, with a long-range program for rechecking, would be useful.

HORIZONTAL EARTH MOVEMENT, VICINITY OF SAN FRANCISCO

COMMANDER WILLIAM GIBSON

The geodetic data that have been accumulated since 1880 in the San Francisco Bay area form a basis of a study of earth movements and disclose evidence of a continuous drift motion. The primary triangulation in this area was first observed in 1880 and later reobserved in 1906, 1923, and 1947.

When the 1947 observations were compared with the 1923 data, differences were encountered which were larger than could be expected from observational errors. A section of the original scheme near San Francisco consisting of points on both sides of the San Andreas fault was selected for further study. Observations had been made over this section in each of the four different periods. The final data obtained from four separate adjustments were compared. The usual method of comparing changes in position was used, but, in addition, changes of azimuth and length of individual lines were computed. These latter differences furnish geodetic data that are far more conclusive than those of the positional shift method. The data obtained show that there has been a continuous movement with the area on the west side of the fault moving north relative to the area on the east side. The rate of motion of this displacement is about 5 centimeters per year.

Additional observations are being made in 1948 in an effort to determine the geographical limits of the area in which these movements are occurring. The primary arc of triangulation along the coast is being reobserved both north and south of San Francisco.

ON A LAYER OF RELATIVELY LOW WAVE VELOCITY AT A DEPTH OF ABOUT 80 KILOMETERS

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Seismograms recorded at epicentral distances between 4° and 26° were investigated, and revised travel-time curves for P and S constructed.

Both consist of two branches, the first almost a straight line ending in a shadow zone, the second beginning with relatively large amplitudes and with a delay relative to the first branch. The end of the shadow zone for P seems to be near 15° in most regions; for S this distance seems to vary somewhat and to be usually a few degrees greater.

Huancayo, Peru, seismograms from near-by earthquakes at intermediate depth were used to study the change of amplitude with focal depth at a given distance in and near the shadow zone. All observations are explained on the assumption that the velocity of P- as well as S-waves decreases somewhat (between ½ and 3 per cent?) at a depth below the Mohorovičić discontinuity to a minimum value at a depth near 80 to 100 km. The data do not permit decision whether the decrease in velocity

is gradual over a range of about 50 km or (almost) sudden at a given depth. The layer with lower velocity extends downward to a depth of about 150 to 180 km; below, the velocities increase rather rapidly, but Poisson's ratio remains near 0.30, contrasting with a value to slightly less than $\frac{1}{4}$ in the upper layers. Correspondingly, the rigidity remains relatively small as compared with the bulk modulus, apparently down to the surface of the core.

It is noteworthy that only a relatively small decrease in velocity is required to produce a rather extensive and pronounced shadow zone.

MICROSEISMS IN NEW ENGLAND—CASE HISTORY II

L. DON LEET

R.F.D. Harvard, Mass.

Rayleigh waves recorded on the three components of the Harvard station are used to determine the direction of approach of microseisms. In Case History I, it was observed that microseisms did not radiate exclusively from the center of a well-developed low-pressure storm area and that they remained strong and continued for many hours after the storm center moved inland over Nova Scotia, northeast of the Harvard station, coming at that time from east, southeast, and south. In Case History II, a short but distinct microseismic storm ran its course as a cold front advanced to the coast and out over the ocean, but there was no atmospheric storm system within the region covered by the U. S. Weather Map.

It is proposed that microseisms are generated when a pressure gradient of magnitude as yet undefined moves over the crust and, in effect, kneads the surface layer in such a way as to set up vibrations.

CALIFORNIA EARTHQUAKES IN 1812

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Earthquakes in 1812 produced the most widespread destruction of mission properties and the greatest loss of life of any year during the Spanish and Mexican regimes in California, and that year was generally referred to as *el año de los temblores*. In the course of time various confusions arose as to dates and happenings, and damaging earthquakes were assigned to locations where they apparently did not occur. An account of the phenomena derived from a study of the early records will be presented concerning the earthquakes of December 8 and 21 and their aftershocks in southern California, and reasons given for considering the later reports of damage to Missions Santa Clara and San Jose, and to the Presidio of San Francisco, as not authentic.

MONTANA EARTHQUAKE OF NOVEMBER 23, 1947

STEPHEN W. NILE

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The earthquake which jolted Montanans awake at 2:46 a.m. on November 23, 1947, produced widespread and notable effects. Instrumental data place the epicenter near the divide between the Upper Ruby River Valley and the Red Rock River Valley. Field data at hand is in agreement with the epicenter mentioned. The quake caused considerable damage at Virginia City, located not far from the epicenter, and caused appreciable damage in the widely separated cities of Butte, Livingston, Great Falls, and Hamilton in Montana, and in Pocatello, Idaho. The quake was felt throughout most of Montana, in bordering counties of Idaho, and in northern Wyoming. Rock slides occurred on both east and west flanks of the epicentral regions, and new water and mud springs were created by the quake. The quake was recorded at seismograph stations all over the United States, and useful records were obtained from such distant stations as those at Sitka, San Juan, La Paz, and Tacubaya. Because of the physical effects produced at the surface and some unusual features exhibited in the seismograms, this quake has aroused the interest of laymen and seismologists alike. In this paper,

the author will discuss the field and instrumental data obtained in connection with this earthquake. Additional important field data are expected to become available when the melting of deep snow permits observers to enter the heart of the epicentral region.

COINCIDENCES IN CALENDAR DATES OF EARTHQUAKES

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Attention has been called to pairs of earthquakes occurring on or near the same date in different years, at nearly the same geographical location.

A statistical investigation of the relative frequency of these occurrences, by comparison with Poisson's exponential function, indicates that it is consistent with the hypothesis that earthquakes are distributed at random geographically and throughout the year.

PASTO (COLOMBIA) EARTHQUAKE OF JULY 14, 1947

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This earthquake reached an intensity of 9 in the epicentral region. From the distribution of intensity it is concluded that the earthquake waves were more easily propagated along the mountain chains and that the focus was relatively shallow.

AFTERSHOCKS OF THE MANIX EARTHQUAKE

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Times of the Manix earthquake of April 10, 1947, in the central Mojave Desert, and of its aftershocks, as recorded at the nearer seismological stations, indicate a distribution of epicenters along a belt extending east of south from that of the main shock. Such a line is transverse to the Manix fault on which small strike-slip displacements were found. Decreasing depth is indicated for the more southerly shocks. Comparison is made with data on wave propagation and structure for other shocks in southern California.

PROGRESS REPORT OF SEISMOLOGICAL WORK BY THE UNITED STATES COAST AND GEODETIC SURVEY IN 1947

FRANKLIN P. ULRICH

Old Mint Building, Fifth and Mission Streets, San Francisco, Calif.

This paper is the annual progress report of the United States Coast and Geodetic Survey on collecting information on felt earthquakes in the Western United States; the strong motion seismological program; the vibration program; the co-operation with other organizations in instrumental upkeep or maintenance; and the co-operative seismological program in the American Republics.

ABSTRACTS OF PAPERS PRESENTED AT MEETING IN LARAMIE, MAY 15, 1948

ROCKY MOUNTAIN SECTION OF THE GEOLOGICAL SOCIETY OF AMERICA

GEOLOGY OF THE KENNADAY PEAK-PENNOCK MOUNTAIN AREA, CARBON COUNTY, WYOMING

WILLIAM H. ASHLEY

The geology of a 62 square mile area, at the northern end of the Medicine Bow Mountains, east of Saratoga, in south-central Carbon County, Wyoming, is discussed. Included with the report is a detailed geologic map and structure section, drawn to a scale of 1:31, 680.

Pre-Cambrian rock and sediments from Mississippian to Jurassic are present in the mapped area. Cretaceous rocks are covered by alluvium, and the Tertiary is represented by strata of Paleocene (?) and early Pliocene age.

Three major north-northeast trending folds, Pennock Mountain anticline, Cedar Pass syncline, and Bitter Creek anticline, all located adjacent to each other from west to east, lie within the east-central portion of the mapped area. Pennock Mountain fault, a low-angle, west-dipping thrust fault, trends northeast in the eastern portion of the area and places late Paleozoic and early Mesozoic rocks on the west flank of Cedar Pass syncline in fault contact with rocks of the same age on the east flank of Cedar Pass syncline.

The history, lithology, and origin of the upper North Park (?) Tertiary in the map area is discussed. The age of the upper part of the North Park (?) formation is definitely determined to be early Pliocene on the basis of the following vertebrate fauna: *Nannipus retrusus*, *Merycodus furcatus*, *Merycodus* cf. *burgensis*, *Procamelus* cf. *occidentalis*, *Turtle* (indet.), and Gomphotheriidae (indet.).

The geomorphology of the Platte Valley pediment surfaces and of Kennaday Peak, a 10,500-foot peak capped by Hanna (?) conglomerate, is considered. The geologic history of the area and its local features are discussed.

MIRABILITE DEPOSITS AT THE SOUTH END OF GREAT SALT LAKE, UTAH

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The mirabilite deposits at the south end of Great Salt Lake, Utah, are concentrated in the vicinity of Saltair Resort and immediately southwest of Black Rock Resort.

A detailed study of these deposits was made from March 1947 to March 1948. On February 1, 1948, the lake was at zero level, an arbitrary point established on the Saltair gauge to determine rise and fall of the lake level. At the zero level, the lake waters were saturated for Na_2SO_4.

Thousands of tons of mirabilite separate from the lake water during winter storms. Onshore winds with resulting wave action cause clusters of mirabilite crystals to accumulate, on the extremely low-angled beach of oölitic sand, as granular masses of various shapes from a few tens of feet to hundreds of feet long and as much as 3 feet thick.

During warm spring rains the winter harvest of mirabilite is dissolved and carried down through the oölitic sand and reprecipitated where it accumulates as part of a permanent bed of mirabilite on gray, micaceous, plastic clay. This bed of secondary mirabilite is as much as 4 feet thick and is protected during the summer months by a covering of oölites that averages 20 inches thick.

The deposits in the two areas mentioned are estimated to contain several million tons of mirabilite of the following composition: SO_4—28.4%, Na_2O—15.08%, K_2O—0.36%, MgO—0.16%, H_2O—45.5%, $CaCO_3$ and SiO_2—10.0%.

STRUCTURAL RELATIONSHIPS OF THE NORTHEAST MARGIN OF THE LARAMIE MOUNTAINS, WYOMING

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An area adjacent to the pre-Cambrian core of the Laramie Mountains extending northwestward from Cottonwood Creek to La Prele Creek has been mapped. The sedimentary sequence ranges

from Cambrian (?) to Upper Cretaceous and is approximately 4200 feet thick. All Mesozoic rocks younger than the Upper Cretaceous Niobrara formation are unconformably overlain by a succession of Oligocene and Miocene continental deposits. The area was deeply eroded after Laramide deformation, and the late Tertiary sediments lie with angular unconformity upon all older strata as well as extensively overlapping onto the pre-Cambrian crystalline rocks.

The Paleozoic and Mesozoic strata near Cottonwood and Horseshoe creeks dip steeply eastward with the development of local, marginal folds which have eastward-dipping axial planes. High-angle faults trend N. 30°–60° E. and offset the sediments by strike-slip movement of at least 2½ miles. The faults also offset the pre-Cambrian rocks. There has not been a consistent pattern of movement of one wall relative to the other. The deep re-entrant of Paleozoic strata immediately northwest of Esterbrook P. O., Wyoming, may be controlled by a similar fault.

Folds west of LaBonte Creek and south of the Platte River are strongly asymmetric with northeasterly dipping axial planes. In two cases the steep flank of the fold is broken by a thrust fault dipping northeast. Pre-Cambrian granite and schist are exposed in the eroded core of two of the anticlines.

The relationship of the trend, extent, and asymmetry of the folds to the regional tectonic pattern is considered. Regional effect of pre-Cambrian structural control upon the Laramide deformation is suggested.

PRE-CAMBRIAN STRUCTURAL GEOLOGY OF THE MT. OLYMPUS QUADRANGLE AREA, LARIMER AND BOULDER COUNTIES, COLORADO

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The Mt. Olympus quadrangle is underlain chiefly by the Big Thompson series of metasedimentary rocks and the Longs Peak (Silver Plume type and age) and Mt. Olympus granites and associated rocks of the Longs Peak—St. Vrain batholith. Although the area underlain by the main part of the batholith is west of the area considered, rock structures of the quadrangle are the result of the emplacement in the quartzites, gneisses, and schists of a multitude of large and small intricately related bodies of granite and pegmatite derived from the magma of the batholith.

A number of long, subparallel, southeast-trending shear and shatter zones, which pass into faults, traverse the rocks of the area. The chief fractures bound uplifted blocks of granite and gneiss. Major ones include the Crozier Mountain and Quillan Gulch shear zones, the Park Hill fault, and the branching shatter zone of Pierson Park. Pre-Cambrian pegmatites of post Mt. Olympus age sealed some of the breaks.

The primary rifts established in the pre-Cambrian were reactivated more than once, particularly during Laramide mountain building.

RANGE OF COMPOSITION OF ORTHOPYROXENE AND OLIVINE MINERALS IN THE LARAMIE RANGE, WYOMING

GEORGE W. DEVORE

There is a striking parallelism in the changes in composition of orthopyroxene, olivine, and plagioclase in a collection of widely distributed samples from the anorthosite-syenite-norite complex of the Laramie Range, southeastern Wyoming.

In 67 specimens of orthopyroxene studied, the optically determined molar percentage of enstatite varies from En_{78} to En_{47}. Oriented clinopyroxene lamellae are present in all specimens. Minor changes in temperature caused significant differences in the composition of the orthopyroxene in the anorthosite; in general, as the anorthite content of the anorthosite increases the enstatite content of the orthopyroxene increases. Orthopyroxene contained in the syenite commonly has a composition of En_{64}, a value also common in the anorthosite body. Range of composition of orthopyroxene in the norite bodies is from En_{62} to En_{47}, values slightly higher than those in the surrounding anorthosite. Orthopyroxene in syenite and norite shows little change in composition within a single body but varies significantly from one body to another.

Olivine is found in anorthosite, syenite, and as a gangue mineral in the magnetite-ilmenite deposits. The range of molar percentage of forsterite in 40 specimens is from Fo_{87} to Fo_{41}. The composition of olivine in the anorthosite is remarkably constant over the area (Fo_{87}–Fo_{80}). Olivine in the syenite

shows a range of composition from Fo_{82} to Fo_{61}. The variation of composition of olivine is more significant between rock types than within a single rock type.

PALEOGEOGRAPHY AND SEDIMENTATION IN THE WIND RIVER BASIN, WYOMING

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The structural pattern of the Rocky Mountain-Great Plains area, established in the Proterozoic, persisted until near the middle of Upper Cretaceous time. The Wind River Basin of Central Wyoming occupied a platform area intermediate between the mobile Cordilleran geosyncline to the west and the relatively stable lands bordering the Canadian Shield to the northeast. In thickness of sediments, the Wind River Basin, with 15,000 feet, was intermediate between the 90,000 feet which accumulated in the Cordilleran trough and the few hundred feet on the margins of the shield in North Dakota and Minnesota.

A series of 17 paleogeographic maps has been prepared. The maps are consecutively superimposed on a regional base map of the Rocky Mountain-Great Plains region. This device graphically shows the persistence of seaways, land barriers, and areas of sedimentation from the pre-Cambrian basement to the Cretaceous. The relationship of sedimentation in Central Wyoming to the land areas and epicontinental seas is discussed briefly for each system of rocks.

CONTRIBUTION TO THE PETROLEUM SOURCE BED PROBLEM

BERNARD J. FERRIS

The significance of the occurrence of bitumen in pre-Cambrian crystalline rocks and in red beds is considered, and the results of studies of certain carbonaceous shales, marine limestones, and lacustrine oil shales as possible source beds of petroleum are presented. Deductions are drawn and recommendations made for future studies.

PETROFABRICS AS APPLIED TO LIMESTONE RESERVOIR PROBLEM

R. B. HOLT

The principles of interpretation of petrofabric diagrams are reviewed, and reference is made to the basic work of Bruno Sander on the Triassic limestones and dolomites of the Tyrol. Petrofabric diagrams of limestones illustrating preferred and random orientation of calcite and dolomite grains are presented and discussed. The effect of deformation, especially jointing, on the preferred orientation of such rocks is considered. The ability of ground waters to penetrate limestones which exhibit preferred orientation is compared to such entry into limestones of random orientation. It is concluded that, other things being equal, a limestone of random orientation is more susceptible to solution with the consequent development of secondary openings than is a limestone of preferred orientation. Ramifications of the solution action of ground water are summarized.

MARINE JURASSIC AND RELATED ROCKS OF LARAMIE BASIN, WYOMING

GEORGE N. PIPIRINGOS

Sections to determine north-south stratigraphic changes were measured at the following localities: E. Freezeout Hills—SE¼ sec. 33, T. 26 N., R. 79 W.; E. Freezeout Hills—SW ¼ sec. 29, T. 25 N., R. 78 W.; Flattop anticline—NE ¼ sec. 22 and NW ¼ sec. 23, T. 23 N., R. 78 W.; Como Bluff—NE ¼ sec. 18, T. 22 N., R. 77 W.; Centennial—NW ¼ sec. 3, T. 15 N., R. 78 W.; Red Mt.—NW ¼ sec. 16, T. 12 N., R. 76 W.; and Bull Mt.—SW ¼ sec. 9, T. 11 N., R. 76 W.

The investigation to date warrants the following conclusions. The Sundance formation thins southward so that the Redwater shale interval is absent south of Centennial Valley, and the Stockade Beaver and Canyon Springs sandstone members of the Black Hills section are absent south of the first section. The Nugget (?) sandstone is provisionally recognized as far south as Centennial, and a conglomerate below this unit was traced into the middle of the type Jelm. The Nugget (?)-Alcova interval is believed to be correlative with the lower portion of the type Jelm. The Alcova limestone is absent south of the Freezeout Hills. The contact of the Jelm and Chugwater at Bull Mountain is marked by a conspicuous erosional unconformity.

The following relationships are suggested.

The Lower Sundance thins by onlap; the Upper Sundance by intra and interformational erosion. The uppermost glauconitic sandstone, best developed in the second Freezeout section, bevels the underlying members and constitutes a new member of the Sundance. The Lak-Redwater shale interval, best developed at Como Ridge, is considered a new member of the Sundance. The Lak and Hulett sandstone members are absent south of the Freezeout Hills. The type upper Jelm included Sundance and Nugget (?) rocks. The Jelm is here restricted to strata below the Nugget (?) sandstone.

MODIFICATION OF BLACKWELDER'S SEQUENCE OF PLEISTOCENE GLACIATION IN THE WIND RIVER MOUNTAINS, WYOMING*

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The threefold sequence of glaciation described by Blackwelder in 1915 is found to be more complex when examined in detail. Gravel on each of two high terraces can be traced into till of the Buffalo stage which suggests that this oldest till may represent two stages or substages of glaciation. Included in Blackwelder's Bull Lake stage are two substages represented by two moraines with related outwash terraces developed below them. Blackwelder's Pinedale stage can similarly be divided into two substages represented by two moraines with related outwash terraces. A third moraine, at altitudes of 9600 to 10,000 feet, has a related outwash terrace and is considered a third substage of the Pinedale because of its similar character. Moraines in front of existing glaciers, moraines in empty cirques, and some protalus ramparts represent the latest readvance of the ice. Criteria for the identification of these moraines and terrace deposits are distinct in any one locality but are necessarily relative from one part of the range to another.

The seven terraces related to the morainal sequence in the Wind River Mountains have been traced down the Green River to the Flaming Gorge and up Blacks Fork into a similar morainal sequence in the Uinta Mountains. They have also been traced down the Wind River to Wind River Canyon. Each terrace is cut into bedrock beneath the gravels of its predecessor.

A tentative correlation is made with the glacial sequence described by Bryan and Ray (1940) in the Front Range of Colorado, but no positive means has been found to correlate with Pleistocene chronology beyond the Rocky Mountains. (*See* accompanying chart, page 1401.)

FLUORINE HOT SPRINGS AT PONCHA SPRINGS, COLORADO

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A composite sample from the hot springs at Poncha Springs, near Salida, Colorado, contains 12 parts per million of fluorine. This amount of fluorine is larger than that for most of the published examples of fluorine-bearing hot springs. The water has a temperature of about 153° F. A terrace of calcareous tufa deposited at the springs consists mainly of calcite with small amounts of opal, chalcedony, siliceous diatoms, quartz, chlorite, and fluorite.

The pre-Cambrian country rock was extensively faulted during late Tertiary time. Lavas, ranging from rhyolite to andesite, crop out within several miles of the springs. The hot springs may represent the closing phase of the mineralization which formed a near-by fluorspar deposit and may be related to the magma chamber which supplied the lava for the flows in the vicinity.

MINERALOGY AND STRUCTURE OF THE PEERLESS PEGMATITE, KEYSTONE, PENNINGTON COUNTY, SOUTH DAKOTA*

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The Peerless pegmatite, at Keystone, South Dakota, is mineralogically and structurally one of the more complex pegmatites in the United States. It has been mined by open-pit and glory-hole methods for mica, feldspar, beryl, and amblygonite.

* Published by permission of the Director, U. S. Geological Survey.

TENTATIVE CORRELATION CHART
Richmond
Blackwelder (1915)

TENTATIVE CORRELATION CHART

Blackwelder (1915)		Richmond				Bryan and Ray (1940)		
Glacial stage	Terrace	Moraine	Terrace	Pinedale	Big Island Green River	Moraine	Canyon terrace	Piedmont terrace
Recent ice		Recent ice	flood plain	flood plain	flood plain	Recent	#1 6–12 ft.	flood plain
						Sprague	#2 25 ft.	
interglacial		interglacial						
Pinedale stage	Lenore	Pinedale 3	2c	4–6 ft.	8–15 ft.	Long Draw	#3 35 ft.	Kuner 12 ft.
		interstadial						
		Pinedale 2	2b	20 ft.	25–55 ft.	— — — — —	— — — — —	— — — — —
		interstadial						
		Pinedale 1	2a	35 ft.	95–125 ft.	Corral Creek	#4 50 ft.	Kersey 25–30 ft.
interglacial		interglacial						
Bull Lake stage	Circle	Bull Lake 2	3b	60 ft.	135–215 ft.	Home	#5 90 ft.	Pleasant Valley 50 ft.
		interstadial						
		Bull Lake 1	3a	80 ft.	240–250 ft.	Twin Lakes	#6 100+ ft.	?
interglacial (canyon cutting)		interglacial (canyon cutting)				(canyon cutting)		
Buffalo stage	Black Rock	Buffalo till	4b	270–320 ft.	340–380 ft.	Prairie Divide		
			4a	350–400 ft.	400–460 ft.			

The pegmatite crops out as an irregular, somewhat lenticular body as much as 585 feet long and 360 feet wide. At the south end it is discordant and at the north end it is partially concordant with the quartz-mica schist wall rock. A cross section through the south end shows three major anticlinal and two synclinal rolls that plunge northward. A fault zone, 25 feet wide, cuts the pegmatite at the north end of the main pit. The individual normal faults strike about N. 70° W. and dip vertically or steeply southwest.

Eleven distinct mineralogical and textural units have been mapped in the Peerless pegmatite. Seven of these are zones, three are replacement units, and one is a fracture filling. These types of pegmatite, in order of decreasing age, are: (1) plagioclase-quartz, (2) albite-quartz, (3) quartz-plagioclase-muscovite, (4) perthite-quartz-albite, (5) albite-quartz-muscovite, (6) quartz-microcline, (7) quartz, (8) quartz-lithia mica-albite (replacement unit), (9) muscovite-albite-quartz (replacement unit), (10) lithia mica-albite (replacement unit), and (11) quartz (fracture-filling unit). Veins of euhedral pink tourmaline crystals cut the replacement and other units. The zones are roughly parallel to the wall-rock contacts. The replacement units cut across zonal boundaries and in places contain relict textures of zones.

MANGANESE DEPOSITS NEAR CHAMBERLAIN, SOUTH DAKOTA

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The manganese deposits of central South Dakota crop out along the bluffs of the Missouri River between De Grey and Lake Andes. The manganiferous beds form the Agency-Oacoma zone of the Sully member of the Pierre formation. The zone consists of nearly horizontal gray shale with numerous beds of bentonite and layers of manganese-iron carbonate concretions. In the most thoroughly explored area, about Chamberlain and Oacoma, the manganiferous zone is 40 to 56 feet thick.

During 1946 the U. S. Bureau of Mines drilled 238 bucket drill holes to determine the quality and reserves. The average manganese content of the zone generally is 1–2 per cent. Half of the manganese is disseminated in the shale, and the other half is concentrated in the discontinuous layers of manganese-iron carbonate concretions. In the area from De Grey to Lake Andes the concretions were found to be 3.78 per cent of the manganiferous zone and to average 15.51 per cent manganese. However, in some parts of the area the average concretionary content of the shale increases to 7 per cent, and in other places the average manganese content of the concretions is more than 17 per cent. The total indicated reserves of metallic manganese on the outcrops and under cover of ½:1 is 12,058,254 short tons.

Landslides modify 75–90 per cent of the outcrops. Inspection of the bentonite beds exposed in the walls of the bucket drill holes was useful in determining the displacement of the slides. Certain bentonites can be traced for many miles and are used to detect regional variations in thickness of parts of the Agency-Oacoma zone.

Ground water was found in 35 per cent of the drill holes. This was unexpected because the holes were drilled in "impervious" shale, and most of them were well up the bluffs of the Missouri River or its tributaries. The water entered the drill holes partly along landslide surfaces and varied from seepage to a flow of 10 gallons per minute.

The concretions are extremely fine-grained carbonates of manganese, iron, calcium, and magnesium and contain also silica and bentonite. Chemical analyses indicate that a single homogeneous carbonate is not possible according to the limits of solubility indicated by Winchell. Microscopic study shows that at least two carbonates are present. The concretions are believed to have formed when the shale was deposited.

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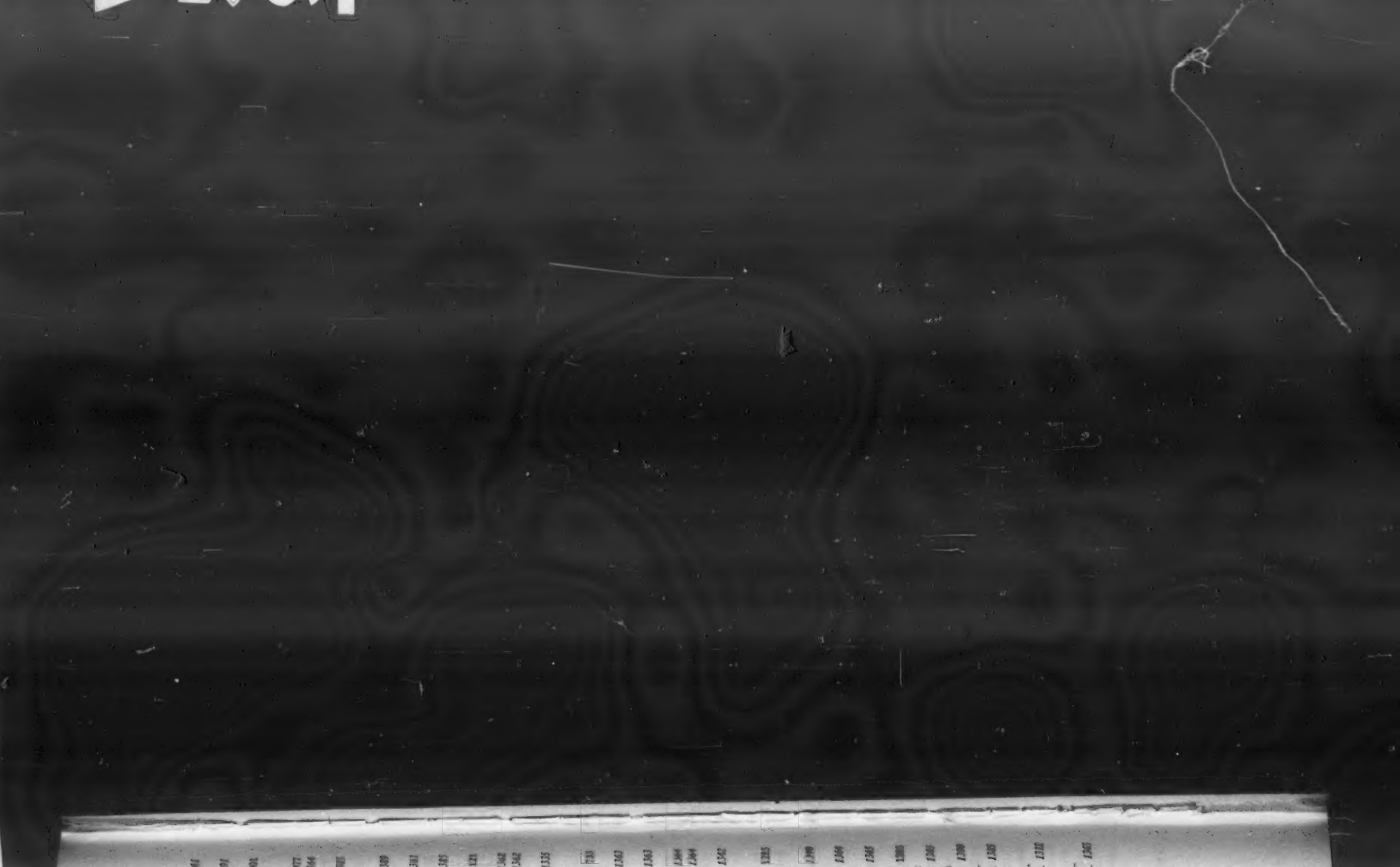
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